UNIVERSITY OF WEST BOHEMIA

FACULTY OF MECHANICAL ENGINEERING

Study program:	N2301	Mechanical Engineering
Study focus:	2302T019	Design of Manufacturing Machines and Equipment

DIPLOMA THESIS

Integrated Conveyor Design with a Focus on Ergonomics and Safety of the Disabled Service

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Consultant:	**Ing. Martin Sirový**

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Fakulta strojní
Akademický rok: 2019/2020

ZADÁNÍ DIPLOMOVÉ PRÁCE
(projektu, uměleckého díla, uměleckého výkonu)

Jméno a příjmení:	**Bc. Tomáš BLÁHA**
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Studijní program:	**N2301 Strojní inženýrství**
Studijní obor:	**Stavba výrobních strojů a zařízení**
Téma práce:	**Konstrukce integrovaného dopravníku se zaměřením na ergonomii a bezpečnost tělesně postižené obsluhy**
Zadávající katedra:	**Katedra konstruování strojů**

Zásady pro vypracování

Základní požadavky:
V úvodu práce bude provedena analýza stávajícího produktu a trhu. V práci bude vypracována specifikace požadavků na produkt. Dále bude vytvořeno několik koncepčních variant a jejich hodnocení. Pro vybranou variantu bude zpracován konstrukční návrh se zaměřením na ergonomii a bezpečnost tělesně postižené obsluhy. Na závěr práce bude vypracována výkresová dokumentace vybraných dílů.

Základní technické údaje:
Technické parametry jsou uvedeny v příloze zadání.

Osnova bakalářské práce:
1. Analýza stávajícího produktu a trhu.
2. Specifikace požadavků na produkt.
3. Vytvoření několika koncepčních variant, hodnocení variant.
4. Konstrukční návrh vybrané varianty se zaměřením na ergonomii a bezpečnost tělesně postižené obsluhy.
5. Závěr.

Rozsah diplomové práce:	**50-70 stran A4**
Rozsah grafických prací:	**dle potřeby**
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HOSNEDL, S.,KRÁTKÝ, J. *Příručka strojního inženýra – Obecné strojní části 1.* Praha: Computer Press, 1999

EDER, W. E., HOSNEDL, S. *Introduction to design engineering.* Boca Raton: CRC Press, 2010

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HOSNEDL, S. *Systémové navrhování technických produktů.* Plzeň: Západočeská univerzita, 2017

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Vedoucí diplomové práce:	**Prof. Ing. Stanislav Hosnedl, CSc.** Katedra konstruování strojů
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Datum zadání diplomové práce:	**16. října 2019**
Termín odevzdání diplomové práce:	**28. května 2020**

L.S.

Doc. Ing. Milan Edl, Ph.D. děkan	**Prof. Ing. Václava Lašová, Ph.D.** vedoucí katedry

V Plzni dne 16. října 2019

Statement of authorship

I hereby submit for assessment and advocacy a diploma thesis, prepared at the end of my studies at the Faculty of Mechanical Engineering of the University of West Bohemia in Pilsen.

I declare that I have prepared this diploma thesis independently, using the professional literature and sources listed in the list that is part of this diploma thesis.

In Pilsen on: …............................ ……………………………….

Author´s signature

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PRACOVIŠTĚ	ZČU - FST - KKS	

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NÁZEV PRÁCE	Konstrukce integrovaného dopravníku se zaměřením na ergonomii a bezpečnost tělesně postižené obsluhy		

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POČET STRAN (A4 a ekvivalentů A4)

CELKEM	107		**TEXTOVÁ ČÁST**	80		**GRAFICKÁ ČÁST**	27

STRUČNÝ POPIS (MAX 10 ŘÁDEK) **ZAMĚŘENÍ, TÉMA, CÍL POZNATKY A PŘÍNOSY**	Diplomová práce obsahuje postup návrhu podle metodiky EDSM (Engineering Design and Science Methodology). Výsledná alternativa byla zde pečlivě vybrána z několika koncepčních návrhů a následně byla provedena komplexní pevnostním a deformačním analýza této alternativy.
KLÍČOVÁ SLOVA **ZPRAVIDLA JEDNOSLOVNÉ POJMY, KTERÉ VYSTIHUJÍ PODSTATU PRÁCE**	Pásové dopravníky, ergonomie, multifunkčnost, přizpůsobitelnost, jednoduchost, MKP analýza

SUMMARY OF DIPLOMA SHEET

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TYPE OF WORK	**DIPLOMA**	~~**BACHELOR**~~	**Delete when not applicable**
TITLE OF THE WORK	Integrated Conveyor Design with a Focus on Ergonomics and Safety of the Disabled Service		

FACULTY	Mechanical Engineering		**DEPARTMENT**	Machine Design		**SUBMITTED IN**	2020

NUMBER OF PAGES (A4 and eq. A4)

TOTALLY	107		**TEXT PART**	80		**GRAPHICAL PART**	27

BRIEF DESCRIPTION **TOPIC, GOAL, RESULTS AND CONTRIBUTIONS**	The diploma thesis contains the design procedure according to the EDSM methodology (Engineering Design and Science Methodology). The resulting alternative was carefully selected from several conceptual designs and then a comprehensive strength and deformation analysis of this alternative was performed.
KEY WORDS	Belt conveyors, ergonomics, multi-functionality, adaptability, simplicity, FEM analysis

Contents:

List of figures:

List of abbreviations:

Al:	Aluminium
CAD:	Computer aided designing
EDSM:	Engineering Design and Science Methodology
FEM:	Finite element method
LC:	Life cycle
PA6:	Polyamide (Nylon)
POM:	Polyoxymethylene
PP:	Polypropylene
Ptc:	Pieces
PU:	Polyurethane
PVC:	Polyvinylchloride
SWOT:	Strengths, Weaknesses, Opportunities, Threads
TS:	Technological System
TS0:	Starting product
TS1:	Designed product
TSA:	Competitive product
TSi:	Ideal product
TTrfP:	Operational Technical transformation Process
TTS:	Theory of Technical System

List of bounded annex:

Appendix no. 1:	Companies which were used as competitors
Appendix no. 2:	Requirements specification
Appendix no. 3:	FEM analysis of the desk holder
Appendix no. 4:	FEM analysis of the back roller holder

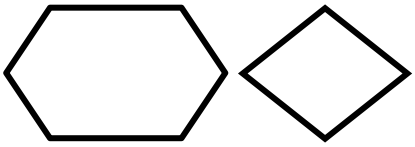
List of enclosed annex:

Drawing of powered roller holder:	DRW-00-00-01 (A3)
Drawing of conveyor assembly:	DRW-00-00-00 (A1)

List of the essential graphic symbols (EDSM):

- **Process, transf. / tech.transf. process (TrfP/TTrfP)**

Set of interrelated or interacting activities (possibly structured into subprocesses, operations and steps) that change available input(s) of process / TrfP to the required ouput(s).
(also **sub-process or operation within a process/TrfP**)

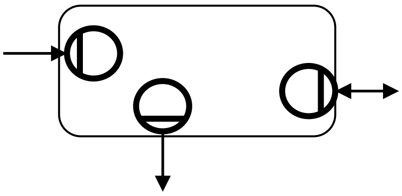


- **Decision process**

(within a process, incl. TrfP)
Set of interrelated or interacting **activities** (possibly structured into subprocesses, operations and steps) **that generate one of the possible alternative of ouput(s) based on evaluation of its input(s) .**

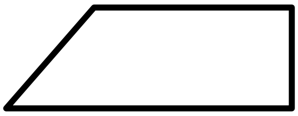
- **Operator (Op)** in transf./tech.transf. system (TrfS/TTrfS)

Transforming M, E, I, or L **object** (tangible or intangible object system) **/** means
(in case of lack of space only operator name at the symbol of its effect)



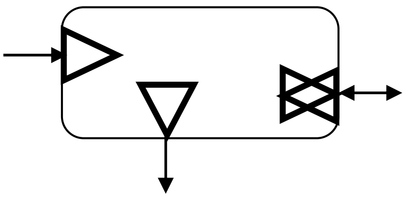
- **Receptor (Rec), effector (Eff)** of tech.syst.(TS)

(TS-cross-boundary elements in general)
Elements mediating M, E, I TS **inputs and outputs with TS**
(also **with operator** or a tangible **object system** (object) in general)



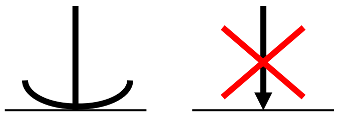
- **Function (Fu)** of technical system (TS)

Capability of a TS abstract organ or TS concrete constructional organ to operate
*(expressed by **infinitive** form),* e.g.:
= operative functions: rotate, cool, hold, …
= passive functions: rotation - , cooling -, holding -, …
permit (enable, …)
***(output operator function** comprises its ability to achieve a required*



- **TS-cross-boundary functions (RecFu, EffFu)** of TS

(boundary elements of TS-function structure)
Mediating function of M, E, I inputs and outputs with TS:
Receptor („input") **function -** left
Effector („output") **function -** in the middle
Receptor-effector („bidirectional") **function** - right
(receptors and effectors may not be necessarily located on TS physical boundaries!)



- **Effect (Ef)** of operator (Op)

(symbol attached to the Op symbol which touches the TrfP symbol, if it is not possible to depict the target object in TrfP):
Action of M, E, I outputs of **operator** (active or reactive, structural or procedural, operative or passive) **including:**

A. Working effects (WrEf) :

a. Needed for transformation of operand (Od) of transformation process (TrfP) or technical transformation process (TTrfP) by subset of **transf. effects (TrEf) in the main transf. process** via a technology *(together with working effects of other operators throughout the whole considered process, e.g. engineering designing, manufacturing, transporting, storing, operating, etc.),* e.g. (*expressed by* ***verbal noun***):
= operative: rotating, cooling, holding, removing, …
= passive: rotating- , cooling -, holding -, removing - , … permiting (enabling, …)

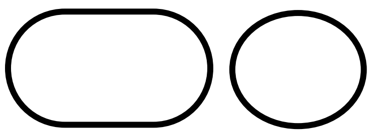
b. Needed for conversions („assisting transformations“) of M, E, I objects in asisting processes of TrfP/TTrfP by subset of **assisting effects (AssEf)** analogously to the transform. effects (see above).

B. Connecting effects (CnEf) :

a. Needed for grounding connection(s) of operator(s) with a basic tangible **object system** (object) or with a **mediating tangible object** (system) connected to it.

b. Needed for carrying connection(s) of operator(s) with carried objects (systems**).**

(Also **mutual M, E, I action(s)** (active or reactive, structural or procedural,



- **Operand (Od)** of transf. / tech.transf. process (TrfP/TTrfP)

Transformed M, E, I, and/or L **object** („object system“as a set of M, E, **I**, L transformed objects in their states between input and output)
(or only operand designation and state at process input/output symbols)
(Also **abstract TS-organ**, **abstract TS-constructional part** , and also **abstract general tangible or intangible object**)

- **Boundary of grounding/carried tangible object** (syst.)

Connection zone with an operator (see Effect, ad B. above)**:**
ad B.a. situated on a **grounding** basic **object** or on **a** mediating **object connected to it** (left part of the symbol)
ad B.b. situated on a **carried object** (right part of the symbol).
(the zone need not be necessarily located on the physical boundaries of the supporting, mediating or a supported tangible object!)

- **Input / output** (Inp/Out) of process, operator , …

Site (if appropriate) and **direction** of the M, E, **I**, and/or L action **input to / output from a process or operator**,
(*however, the symbol is not at the same time the symbol of the operand in its input / output states in context with TrfP!)*
(**vector** in general)

- **Property (Pr)** (incl. functions) of technical systems (TS)

Attribute, characteristic, etc. **of TS** , **which characterizes** it from an inherent viewpoint, incl. its behavior.
(the concept property also concerns **transformation / tech.transf. processes (TrfP/TTrfP),** and tangible and intangible **object systems** (objects), however , the **depicted symbol is not used for them** in general)

[26]

1. INTRODUCTION

Introduction of the topic of work

Belt conveyors are very casual machines used in different types of industries. Most often they are used in machinery, food, and mining industry. In all these types of use are different circumstances, different requirements and of course, different environments also. In the food industry, it is usually requirements for medical harmlessness, and in the mining industry, it is resistance against the dusty and wet environment. This thesis aims to design the conveyor, which allows a disabled operator to work and of course, to offer some friendly and ergonomic workplace to these operators. The next goal will be to suggest opportunities for innovation of this product to make it "SMART".

Introduction of the project MUPIC

This dissertation was solved in parallel with the MUPIC (Multidisciplinary Project in an International Context) project, where the author was cooperating with students from different countries and different fields of study in innovating the required product. In this project were all participants using the English language. Due to that is this dissertation written in the English language.

Introduction of the company ENGEL

Company ENGEL was established by Ludwig Engel in 1945. This company focuses on the manufacturing of injection moulding machines which are used to generate plastic product created from molten plastic. The company's branches are located almost all over the world. Project MUPIC and this dissertation were built on the cooperation with a branch located in the Czech Republic in Kaplice (established in 2000). This branch focuses on the production of components used to assemble injection moulding machines and also on the production of belt conveyors which are used as equipment of these machines. [30]

Figure 1 Injection moulding machine - VICTORY [31]

1.1. Conveyors

Conveyors [1] are machines working mostly on mechanical principle, which allows transporting of the product from place A to place B. During this transporting process can be included some other functions such as drying, mixing, checking, measuring.

Machines for transporting a product can be divided into three groups.

- For bulk material
  - This section consists of vibrating and screw conveyors, stream conveyors, bucket elevators, pneumatic systems, hydraulic systems.
- For piece material
  - Inside this second section can be added roller tables, special elevators, carriage, lifts, hoists, cranes, lifting platforms, and overhead conveyors.
- For bulk and piece material
  - The third section is for us the most important because this section consists of belt conveyors, transporting chutes, and segment conveyor. These machines are very casual solutions to transport the product.

2. ELABORATION OF THE PROBLEM

In the first chapter will be introduced problems which will be solved during the engineering design process. This information is essential to understand the whole integrity of the process and its consequences.

2.1. Establishing requirements specification for TS and project solution plan

2.2. Assignment clarification and completion

In the company "ENGEL" there are produced belt conveyors. These conveyors have a long tradition, and they did not pass through any more significant innovation for 18 years. These conveyors are primarily produced as equipment for injection moulding machines, but they can also be used as a separate transporting machine. The primary goal of these conveyors is to transport some product from place A to place B, but there can be a lot of other functions which can improve the productivity or the quality of production. Company ENGEL knows about this weakness of the conveyor and because of this fact they want to obtain something like "SMART conveyor", but one of the restricting requirements are of course the costs of new conveyor production. Due to this will be needed to calculate the price continuously and try to meet the costs requirement.

After some dialogue with the representative from the company "ENGEL" designer obtained some other requirements and one and most important requirement for us was that they want to obtain some alternative ideas form us. The engineering designer obtained some "freedom" in the engineering design process, but there is a small list of primary requirements from company "ENGEL":

1. The final alternative should meet the costs requirement.
2. The conveyor should be able to work in continuous mode or discontinuous mode, and it should be able to be aligned with the injection mould.
3. It has to allow access to an injection moulding machine during its service.
4. The temperature of the product should be lowered during the transportation process.
5. The final product design should be done in a black and green combination.
6. The final alternative of the conveyor should be the "SMART online device", which allows the disabled operator to use it.
7. It is preferred to use just technologies available in the company "ENGEL".
8. There is preferred work using CAD system NX.
9. The final product should fulfil ergonomic, maintenance, lifetime, safety, and environmental requirements.
10. The production of the final product should be 500 pcs. /year.

11. Required costs were not precisely defined. For rough orientation will be used costs on starting product 838.7 €.

These requirements are just from company "ENGEL" as from the potential producer of this conveyor, but there is much potential requirement from conveyor users. All requirements can be divided into life-cycle phases. In all these phases can be found many requirements from customers (users) and from other people, which will come into contact with this product. These people are users, repairmen, distributors, waste sorters, and others. A unique "Requirements specification" table was created to meet the requirements of the users, see appendix two.

2.3. Problem clarification

The primary goal of this engineering design process will be to get some alternative of conveyor, which will meet the majority of the requirements. There will be more than one alternative, but just one (most interesting and the best alternative) will be processed in further detail. More details about selected alternatives and ideas will be signed later during the engineering design process. The final product should be more attractive for customers, and it should be "SMART and easy to use for handicapped operators".

2.3.1.1. The assumption for the handicapped machine operator

Owing to the assignment of this dissertation "Integrated conveyor engineering design with a focus on ergonomics and safety of the disabled service" is one of the steps needed to create some specification of the potential machine operator. It is necessary to create this specification at the beginning of the engineering design process inasmuch it helps to make the assignment more precise, and it also helps the designer to accelerate the engineering design process.

It is challenging to specify some group of "allowed types of handicaps" to work with designed conveyor. However, this specification has to reduce the amount of potential disabled employees and select those who are probably able to work with this conveyor. Of course, it is necessary to consult this decision with the nursing doctor and naturally with ergo therapist.

A part appendix of ordinance number 359/2009 Collection from Czech legislation called "Percentage rate of workability" was used to select a group of disabled operators able to work with a designed conveyor. The selected part of this document is "Limbs disability", which contains many types of libs handicaps, but it has to mention that this list of limbs handicaps was necessary to limit on just one limb disabled operator.[2]

During the engineering design process will be given special attention to prevent any type of accident between operator and conveyor, but it has to be mentioned that there is a low possibility to prevent all possible accidents or injuries caused by wrong using of the conveyor belt.

2.3.1.2. Specification of transported products

The maximal dimensions of transported products are 300 x 300 x 300 mm. That can be represented as a cube of one side length 300 mm. Minimal dimensions of the transported product are 10 x 10 x10 mm (also can be represented by a cube of side length 10 mm). The maximal weight of one product can be 5 kg, and it should have these properties:

1. Solid surface with no sharp edges which can damage the belt.
2. Clean surface with no pollution (such as liquids or dust) on it.
3. Temperature range from -10°C to +80°C

2.4. Search for the State of the Art

During the research into the market offer and state-of-the-art was found that there are a lot of competing companies, which are producing conveyors, but there are many companies, which produce conveyors for disabled operators. Because of this fact it will be necessary to use just common alternatives of conveyors in the "State Of the Art". Products of these companies are usually based on the belt conveyor, chain conveyor, roller alternative, timing belt conveyor principle and a lot of other alternatives and variations. Usually, there are no alternatives with some modularity, and many products are based on the experienced working principle, because of this fact, it is possible to come up with something new. It can be expected that the biggest competitor on the market is the usual belt conveyor and its variations.
Because the scale of competing companies it too large, there will be selected just a few most interesting and best competitor alternatives of conveyors available on the market.

BM 8410/8420 Narrow, Front drive (INTERROLL)

- Maximal load capacity: 50 kg/m
- Conveyor speed: 0.1 to 2.5 m/s
- Ambient temperature: 0-40°C
- Conveyor belt: 2-layers PVC
- Rated width: 420/620/840 mm
- Module length: 650 – 3000 mm
- Side guide height: 35 – 65 mm

Figure 2 BM 8410/8420 [15]

This product from company "INTERROLL" is possibly the biggest competitor of our potential product. It has a full scale of speeds so it can be easily adjusted to injection mould press. This product also has a proper and safe cowers of the belt, and it is very small and simple. [15]

80C TR (HABERKORN)

- Maximal load capacity: 20 kg/m
- Conveyor speed: 5 – 46 m/min
- Ambient temperature: 10 – 80°C
- Conveyor belt: PVC/PU/Textile
- Rated width: 300 – 1000 mm
- Module length: 600 – 10000 mm
- Roller diameter: 84 mm

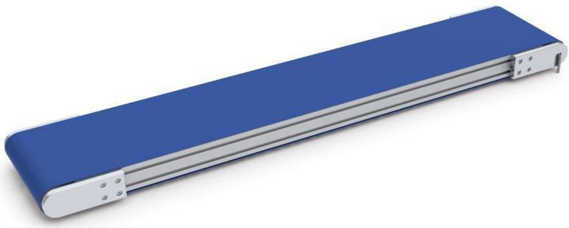


Figure 3 80C TR [16]

This product from company "HABERKORN" has less covering of belt, but it still has a wide range of speeds so it can be easily adjusted too. This product has a vast range of module length, and it offers usage in higher temperatures. Finally, this product also offers to use more than one type of belt. Nevertheless, this product is very similar to VC*/90-120 from company "ENGEL". [16]

C1100 – Linear Conveyor (CRIZAF)

- Maximal load capacity: 20 kg/m
- Conveyor speed: 3.2 m/min
- Conveyor belt: PU
- Rated width: 190 – 790 mm
- Module length: 500 – 7000 mm

Product C1100 from company "CRIZAF" is equipped with the adjustable stand and useful and safe covering of belt and product guidance. However, the most significant disadvantage of this alternative is the fixed speed. [17]

Figure 4 C1100 [17]

Rotary Table DTZ-P 2040 (MK-GROUP)

- Maximal load capacity: 100 kg
- Drive version: Chain
- Table diameter: 750/1000/1250/1500mm
- Height of table: 500 – 1500 mm

Figure 5 Rotary Table DTZ-P 2040 [18]

This product from the company "MK-GROUP" is quite different because of the different principles of work. Nevertheless, it can be considered as a competitor. There is much space to stuck products on this table, and it can carry a big load. However, it is challenging to compare this table conveyor with a belt conveyor. [18]

Modular conveyor (HABERKORN)

- Maximal load capacity: 30 kg/m
- Conveyor speed: 4 – 50 m/min
- Ambient temperature: 10 – 80°C
- Modular belt: PP/PE/POM/PA6
- Rated width: 80 – 1000 mm
- Module length: 600 – 10000 mm
- Roller diameter: 84 mm

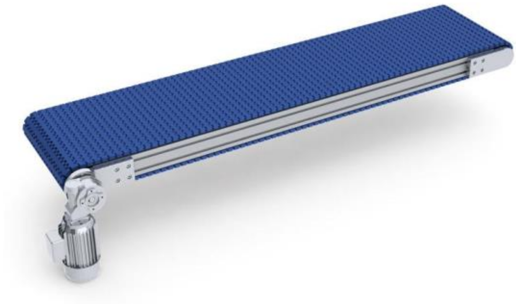


Figure 6 Modular conveyor [19]

This modular conveyor from the company "HABERKORN" has a larger load capacity, and the adjustable conveyor speed range is also a significant advantage. Nevertheless, the engine outside of the roller is a significant disadvantage because of the safety and layout place. Moreover, there is very weak protection against contact with the belt. Therefore this type of conveyor cannot be used for transporting small products, because these products can easily fall through the belt. [19]

Roller conveyor - direct driven (HABERKORN)

- Maximal load capacity: 35 kg/m
- Conveyor speed: 3 - 31 m/min
- Ambient temperature: 10 – 80°C
- Roller material: PVC/ zinc coated/ stainless steel/ Al
- Rated width: 200 – 1000 mm
- Module length: 300 – 13000 mm
- Roller diameter: 50 mm
- Drive: 3 x 400 V

This type of conveyor is beneficial in applications, where are transported heavier and larger products. These conveyors can be used even for long transport tracks but also for short tracks. One significant disadvantage of this type of conveyor is the fact that there cannot be transported smaller products. [20]

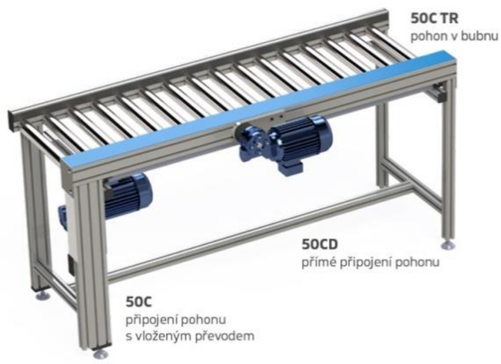


Figure 7 Roller conveyor [20]

Gravity roller conveyor (FEIFER)

- Maximal load capacity: 35 kg/m
- Roller material: Plastic
- Rated width: 300/500/800 mm
- Module length: 1000/1500/2000 mm
- Roller diameter: 50 mm
- Height adjustments range: 580 – 920 mm

Figure 8 Gravity roller conveyor [21]

Gravity roller conveyor is a very cheap and economical solution because there is no drive needed, and the tilt of conveyor can be easily changed. However, there is the same disadvantage as in the previous case, and this conveyor cannot transport smaller objects. [21]

2.4.1.1. Conclusion of the state of the art

As a conclusion of the state of the art, it can be said that the market offer is extensive, but there are usually missing "SMART and adaptable" conveyors with some replaceable equipment. So the "SMART and adaptable" product with some equipment can be very successful on the market, and it can fill the hole in the market offer. There are also no adaptable conveyors for the disabled operator, and that means it is the hole in the market too. Links on all companies which were included in this state of the art can be found in the appendix.

2.4.2. Analysis of patents

Before the start of the engineering design process is necessary to create the analysis of patents. Because of the problem of endless research, there will be stated just the essential patents. During the engineering design process will be examined more patents.

Belt conveyor – EP1710176A2 – B65G23/14 [3]

This patent relates to the method of conveying the belt of the belt conveyor.
The principle of this method:
The engine drives guide roller, and this roller drives the front roller. A thong mediates the connection between these two rollers.

Apparatus and methods for high-speed conveyor switching – US20060070857A1- B65G47/71 [4]

This patent relates to the unique principle of conveyor with adjustable and switchable conveying trajectory.
The principle of this method:
This method allows to conveyor to drive the main rollers and other smaller wheels which are added to sort conveyed products.

Conveyor assembly with air-assisted sorting – US20090272624A1 – B07C5/363 [5]

This patent relates to the principle of removing from the belt.
To the conveyor are connected special air blowers, and the airflow moves the product from belt to some storage place. The use of air blowers depends on the product's mass and dimensions.

Conveyor storage system – US4273234A – B65G47/57 [6]

This patent relates to the storage of products moved by conveyor.
This storage "tower" allows transport continuously from a conveyor on the special holder, where the products are stored.

2.4.3. First engineering design reflection

LIFE-CYCLE and ENGINEERING DESIGN PROCESS

At the beginning of the engineering design process is necessary to think about the product life cycle (LC). This cycle requires some properties of conveyor, and the final engineering design should be the suboptimal alternative in all phases of the LC. Without this thinking can be possible deficiencies found too late (e.g. If the customer will found some deficiency in the operation stage, it is too late to fix it) and much money can be spent to fix caused problems not to mention the bad impact on the company name. This project is trying to avoid these problems using some prediction of the possible deficiencies.

In the beginning, it will be just briefly introduced the importance of life cycle study. For this thesis, the main stages of the products life cycle are Pre-manufacturing, Manufacturing, Distribution, Operation and Liquidation. In all these phases, there are some energies consumed/produced, and emissions or waste produced. The designer can (from his perspective) influence these consumptions and productions by his decisions in the engineering design process. Of course, it is complicated to make whole impact research and count all amount of produced emissions, waste, and consumed energy, but designers can use just the necessary information about these values and use them for making better decisions.

The main stages (for this thesis) of LC will be elaborated, and the requirements from these phases will be introduced. Of course, there cannot be introduced all requirements and due to that will be highlighted and listed just the requirements which are quite crucial for the company and user from the authors perspective.

Pre-manufacturing stage:

In this stage can be considered just the impacts and properties, for example, each material or technologies used on the final product and its impact on the environment. Nevertheless, there is one requirement, which will be most frequently used here: "To use materials that can be recycled and used again".

Manufacturing stage:

The essential requirement resulting from this phase is to use the technology available in the company "ENGEL" or "ENGEL" cooperating companies. Furthermore, the next requirement is to use the cheapest and undemanding alternative for manufacturing.

Distribution stage:

First requirement there can be the fact that the conveyor should allow being quickly packaged into a small object, which could easily be transported and stacked on the top of each other. Of course, it should be light to reduce the transport price.

Operation stage:

There will be many requirements:

- To reduce the weight of the conveyor to help the service to move with it.
- To create an ergonomic and safe product to reduce the possibility of service injury and improve the amenity of the work environment.
- To create a product that will be customized for people with physical disabilities.
- To design a product that will fulfil the customer's requirements.

Liquidation stage:

There is mentioned just one main requirement. All materials should be easily recycled.
During the elaboration of this diploma thesis, and the final product engineering design, the requirements concerning the environment will also be taken into account. [32]

Safety and conveyors

Conveyors are used very frequently, and they are usually used in every company which produces something in large among them. Moreover, these conveyors can sometimes be quite dangerous for the service, because of this fact, it is necessary to focus on the stage of product operation, on some safety elements and the safety perspective itself.
A conveyor is a machine that is used to transport something somewhere. Furthermore, during this process is some service person needed. This service is coming in direct contact with conveyor during this process. There are some moving/rotating/retracting and other movements done by some parts of the conveyor and which means that there are many accident opportunities. Nevertheless, in this case, it is not precautioning enough to reduce the possibility of the accident or injury of service. It is necessary to create some safety elements and covers by the designer, and in the case of this dissertation, it is also needed to think about safety for physically disabled employees.
At first is needed to cover every rotating or just moving parts which can be dangerous (such as belt corners, rollers, strap, engine, gears). These covers should be of course suitable from an ergonomic and industrial design point of view, but primarily it should protect. If we focus for example on belt conveyor, we can say there that is needed to cover corners on the sides of the belt and front and backcrossing of the belt to the lower part. However, all these safety elements should not endanger or limit the primary function of the conveyor. There is one problem which is very difficult to solve "Hairs" if someone is using a conveyor or some other machine it is useful to have the hair tied up.
Nevertheless, there is still some danger of caching the hair in some moving part. Many covers cannot solve problems with hairs because hairs are very thin. So it is better to prevent the service to bend near the conveyor.

2.5. Establishing requirements specification for TS

2.5.1. Requirements specification of TS

In **Figure 9**, a list of requirements is stated. It will also be used in the engineering design process to evaluate designed alternatives and to compare starting product TS0 (in this case it is conveyor from company Engel "HLi 2900Lx350W"), competitive product TSA (in this case it is not conceived like one product, but it is conceived like a set of the best features of competing products) and designed TS1. The purpose of this table is to describe "How the requirements were used and organised", and detailed tables and charts will be listed later.

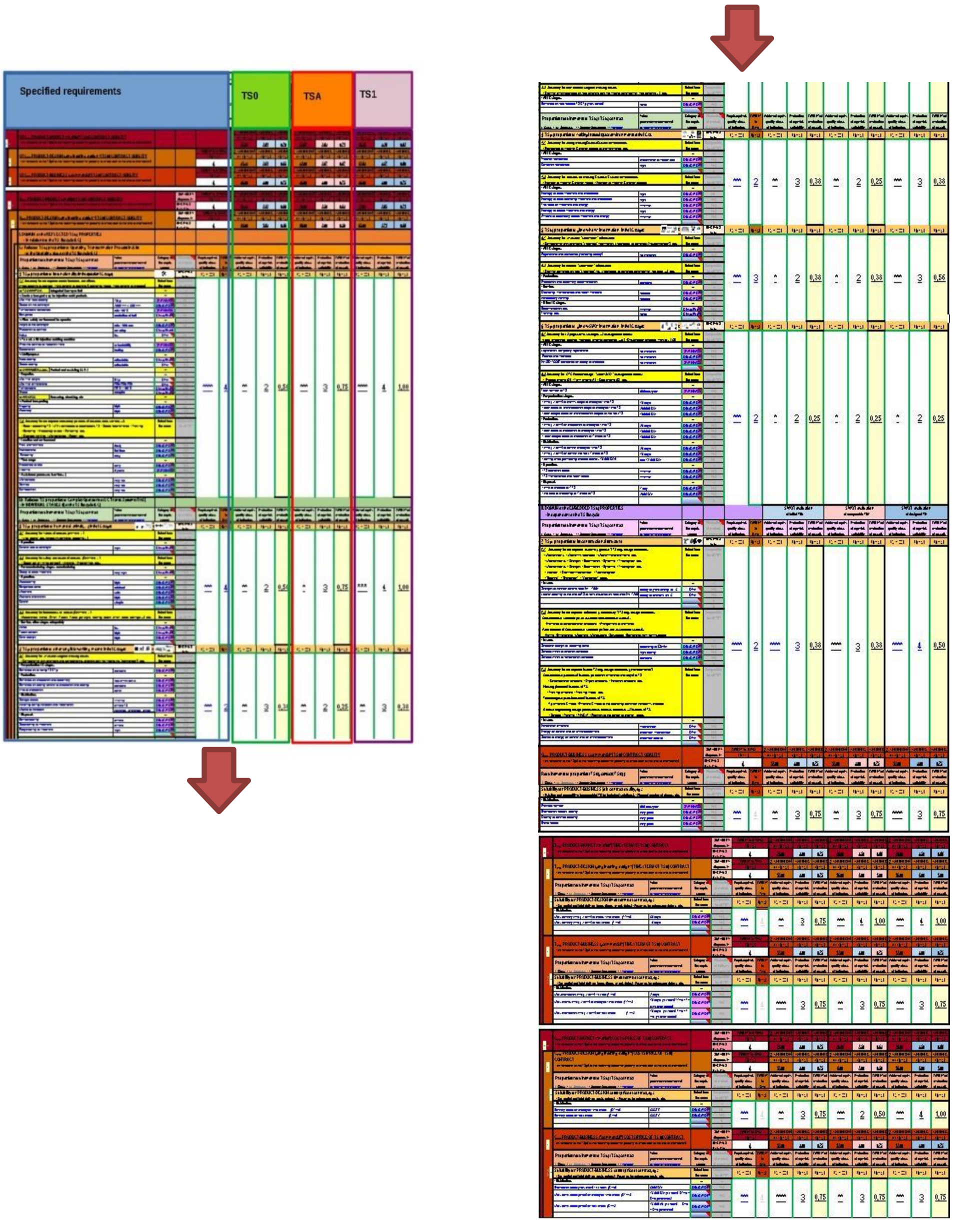
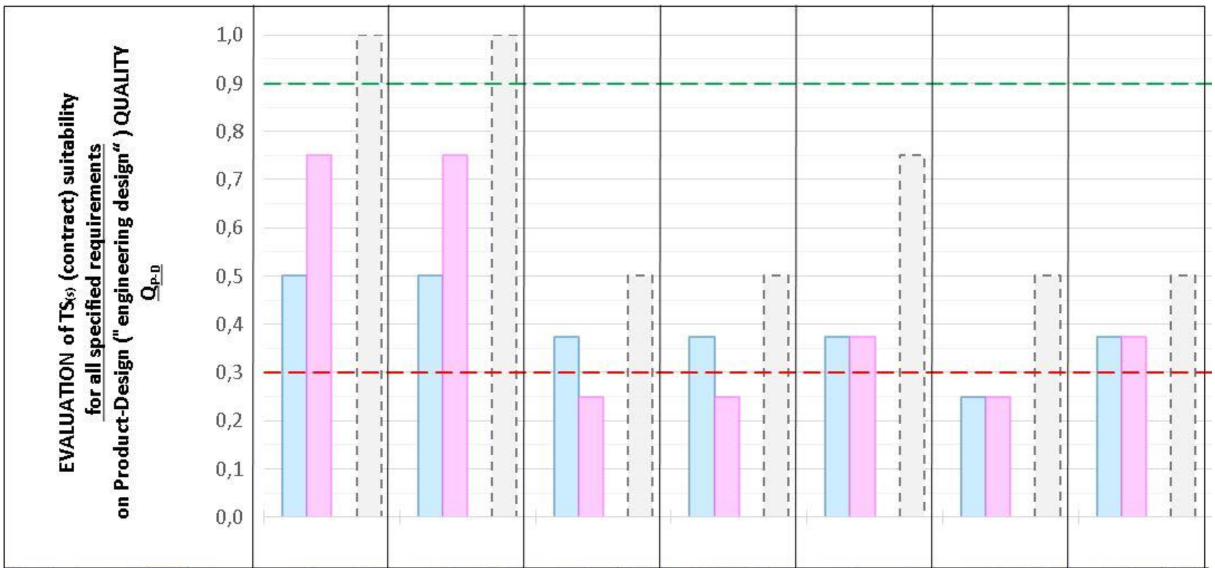


Figure 9 Structure of the TS requirements specification and SWOT evaluation (charts added later) [26]

2.6. Evaluation and analysis of the starting and competitive TS

2.6.1. SWOT evaluation of starting and competitive TS for requirements specification

From the graph shown in **Figure 10**, it can be deduced that the product of company Engel, in this case, has considerable shortcomings in its functionality properties (against the ideal and competitive product) and also in properties to humans. On the other hand, it is preferable and more suitable than the competitive product intangible working means properties and also in properties to the active and reactive environment. In the rest of the properties are the results for starting product and competitive product identical.

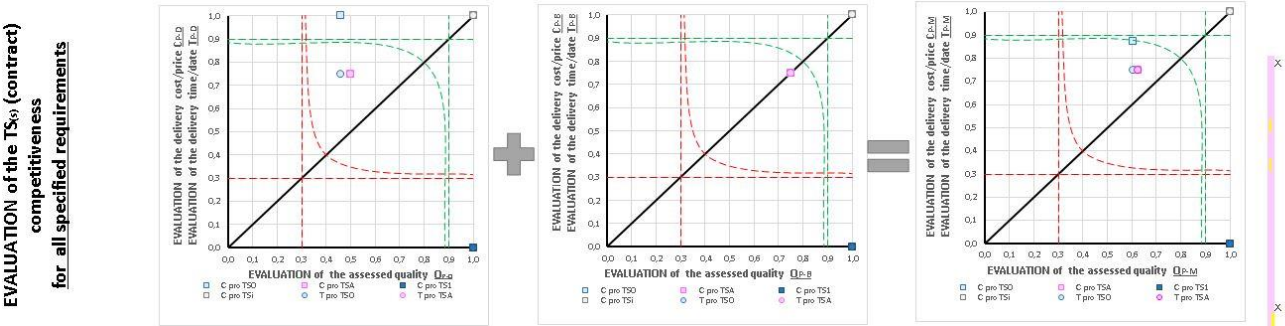


Return to Requirements Specif. & SWOT Evaluation:		◄◄ REQ.SPEC&SWOT	◄◄ REQ.SPEC&SWOT	◄◄ REQ.SPEC&SWOT	◄◄ REQ.SPEC&SWOT	◄◄ REQ.SPEC&SWOT	◄◄ REQ.SPEC&SWOT	◄◄ REQ.SPEC&SWOT
Q_{P-D} class of properties / requirements on TS (contract) :		1. TS(s) properties to its functionality (incl. operability) **TS(s)**	2. TS(s) properties to humans (& animals, ...) **HuS**	3. TS(s) properties to other tangible working means **TS**	4. TS(s) properties to active&reactive environment **AREnv**	5. TS(s) properties to „know-how" information **IS**	6. TS(s) properties to „know-SMQ" information **MgtS**	7. TS(s) properties to its constr.structure (incl.feature&react.pr.) **TS(s)**
TS Life Cycle stage :		operation	all !	all !	all !	all !	all !	indirectly all !
Weight of properties / requirements (0 - 9) :		4	4	2	2	3	2	2
Results of the weighted SWOT evaluation (0 - 1)	Starting TS0	**0,50**	**0,50**	**0,38**	**0,38**	**0,38**	**0,25**	**0,38**
	Competitive TSA	**0,75**	**0,75**	**0,25**	**0,25**	**0,38**	**0,25**	**0,38**
	Designed TS1	---	---	---	---	---	---	---
	Ideal TSi	1,00	1,00	0,50	0,50	0,75	0,50	0,50

Figure 10 Results of SWOT evaluation of the suitability of the starting TS0, competitive TSA and reference ideal TSi for all specified Q(P-D) requirements [26]

2.6.2. SWOT evaluation of the mutual competitiveness of the starting and competitive TS

From the chart shown in **Figure 11**, it is easily visible that in this step, the competitive product is more suitable and more attractive for the customer.



Return to Requirements Specif. & SWOT Evaluation:		◄◄ REQ.SPEC&SWOT	◄◄ REQ.SPEC&SWOT	◄◄ REQ.SPEC&SWOT	◄◄ REQ.SPEC&SWOT	◄◄ REQ.SPEC&SWOT	◄◄ REQ.SPEC&SWOT	◄◄ REQ.SPEC&SWOT	◄◄ REQ.SPEC&SWOT	◄◄ REQ.SPEC&SWOT
Q^T^C area of properties / requirements on the TS (concract):		Q_{P-D} PRODUCT-DESIGN („engineering design") TS(s) CONTRACT QUALITY	T_{P-D} PRODUCT-DESIGN („engineering design") TS(s) CONTRACT TIME / DATE	C_{P-D} PRODUCT-DESIGN („engineering design") TS(s) CONTRACT COSTS / PRICE	Q_{P-B} PRODUCT-BUSINESS („business") TS(s) CONTRACT QUALITY	T_{P-B} PRODUCT-BUSINESS („business") TS(s) CONTRACT TIME / DATE	C_{P-B} PRODUCT-BUSINESS („business") TS(s) CONTRACT COSTS / PRICE	Q_{P-M} PRODUCT-MARKET („market") TS(s) CONTRACT QUALITY	T_{P-M} PRODUCT-MARKET („market") TS(s) CONTRACT TIME / DATE	C_{P-M} PRODUCT-MARKET („market") TS(s) CONTRACT COSTS / PRICE
TS Life Cycle stage :		distribution	distribution	distribution	distribution	distribution	distribution	distribution	distribution	distribution
Weight of properties / requirements (0 - 4) :		4	4	4	4	4	4	4	4	4
Results of the weighted SWOT evaluation (0 - 1)	Starting TS0	**0,46**	**0,75**	**1,00**	**0,75**	**0,75**	**0,75**	**0,60**	**0,75**	**0,88**
	Competitive TSA	**0,50**	**0,75**	**0,75**	**0,75**	**0,75**	**0,75**	**0,63**	**0,75**	**0,75**
	Designed TS1	---	---	---	---	---	---	---	---	---
	Ideal TSi	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00

Figure 11 Results of SWOT evaluation of Q^T^C(P-D)/(P-B)/(P-M) competitiveness of starting TS0, competitive TSA and reference ideals TSi for all comparable requirements on the designed TS [26]

2.7. Establishing project solution plan

2.7.1. Feasibility study

This engineering design process is based on the knowledge of the market and current technology level. During the State of the Art study and market research was found that this project is feasible using the technology level of company ENGEL and available knowledge. It is also feasible, depending on the economic perspective.

2.7.2. Solution strategy

This engineering design process is based on the strategy of a simplified instructive methodology based on the Engineering Design Science and Methodology (EDSM). [26], [32]

2.7.3. Project solution timetable

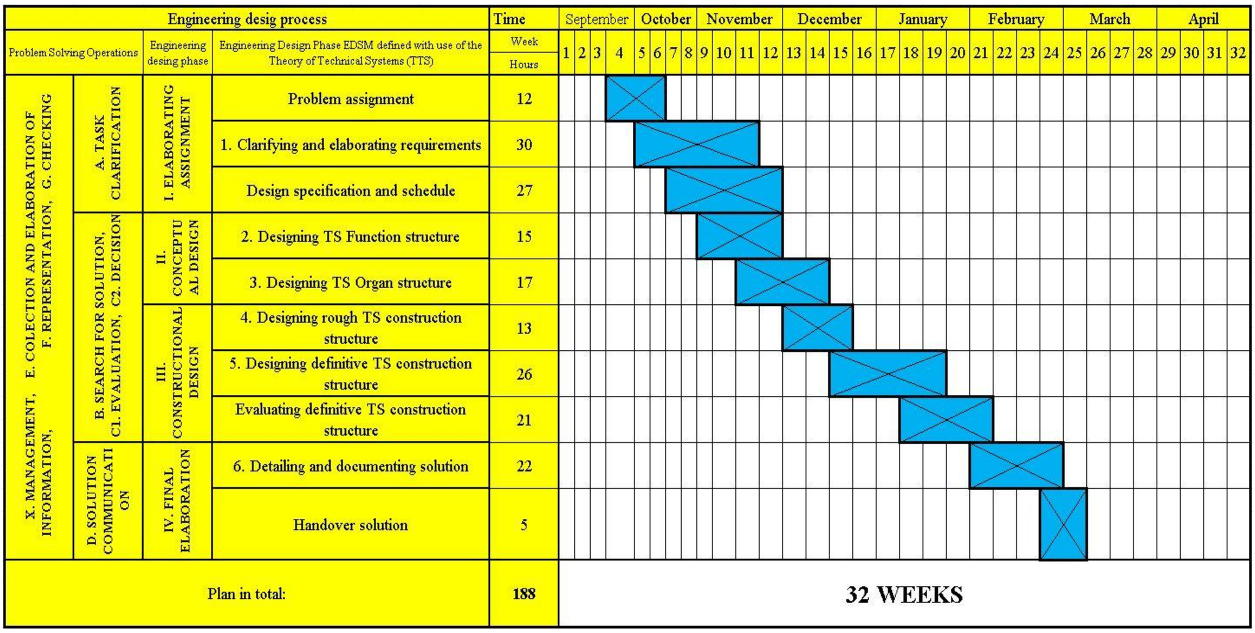


Figure 12 Schedule of the engineering design project of TS [26]

3. CONCEPTUAL DESIGN

3.1. Operational technical transformation process (TTrfP) of TS

3.1.1. Black box of the operational Technical transformation process (TTrfP) of TS

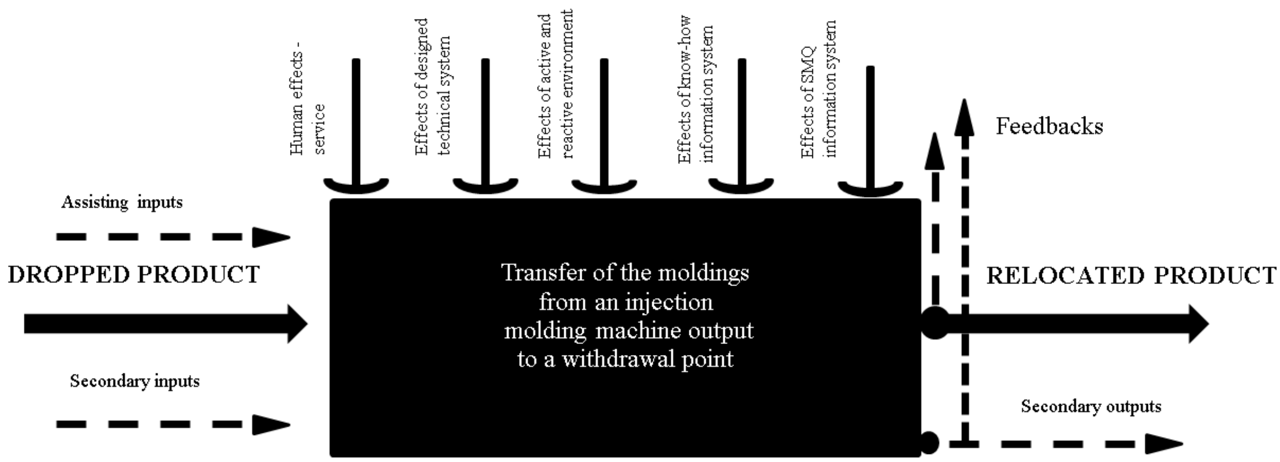


Figure 13 Black box of the operational Technical transformation process (TTrfP) of TS [26]

3.1.2. Technological principle of the operational Technical transformation process (TTrfP)

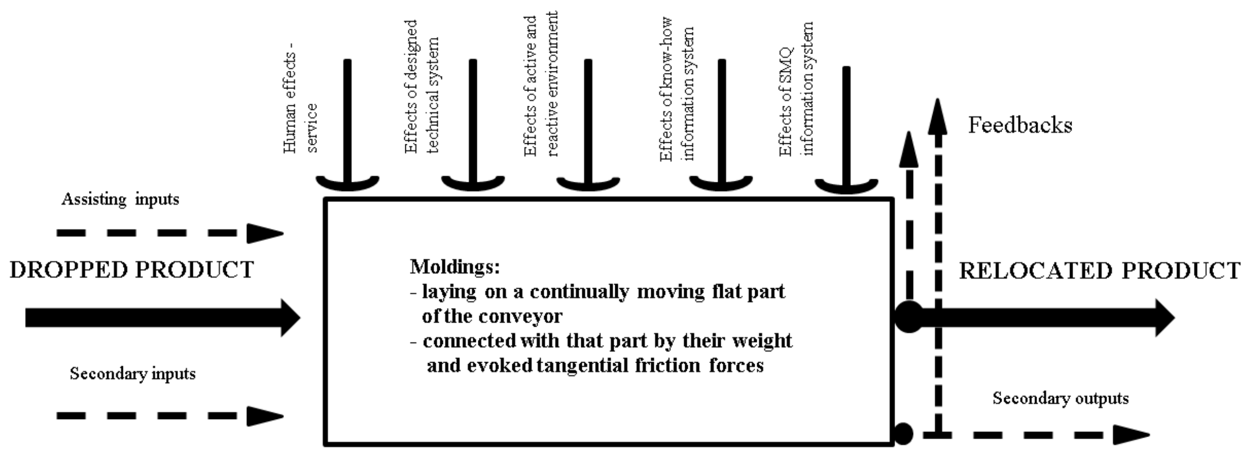


Figure 14 Technological principle of the operational Technical transformation process (TTrfP) [26]

3.2. Engineering Design of TS Organ structure

3.2.1. Engineering design of TS Organ structure alternatives

3.2.1.1. Organs for the designed Organ structure

Organs for the functional structure of TS

Main function of TS and its asistating functions			Organs of TS (function bearers)					
			1	2	3	4	5	6
FUNCTION 1	1.0 To Provide the FEED		BELT	ROTATIONAL TABLE	WORM	CHAIN	V-BELT	VIBRAION DESK
	1.1 To CENTER the belt		BOMBEERING	BELT WITH GUIDANCE				
	1.2 To RUN the belt		HYDRAULIC GENERATOR	ELECTRICAL ENGINE	PNEUMATIC GENERATOR	PETROL ENGINE		
	1.3 To SUPPORT the belt		METAL SHEET	METAL BELTS	ROLLERS			
FUNCTION 2	2.0 To TIGHT the belt		HORIZONTAL PULLEY	VERTICAL PULLEY	WEIGHT	TIGHTED ROLLER		
	2.1 To CHECK the TENSION		SENSOR					
FUNCTION 3	3.0 To TRANSPORT the product	3.1 Material of the belt	PU	PVC	MODULLAR (SPECIAL)	STEEL	TEXTILE	
		3.2 Type of the belt	SHAPED	SIMPLE				
FUNCTION 4	4.0 To secure the SAFETY	4.1 To check the POSSITION of the belt	SENCOR					
		4.2 To COVER dangerous places	COVERING LINES	TUNNEL COVER	COMBINATION	EMBEDED BELT		
		4.3 To allow quick SHUTDOWN	CENTRAL STOP BUTTON	TWO HANDS CHECK	AUDIO (VOICE) SWITCH	COMBINATION		
FUNCTION 5	5.0 To secure the ERGONOMICS	5.1 To allow ADJUSTING	SCISSOR MECHANISM	SLIDING DESK	ANGLED CONVEYOR			
		5.2 To be CONFORTABLE to use	AUTOMATICAL POSITIONING	MANUAL POSITIONING	SPECIAL MATERIAL OF COVERS	COMBINATION		
FUNCTION 6	6.1 To CONNECT conveyor with the machine		A. TYPE OF FRAME	B. TYPE OF FRAME	C. TYPE OF FRAME			
FUNCTION 7	7.0 To make it SMART		TEMPERATURE CHECKING	COOLING	POSITION CHECKING	SURFACE	WEIGHT CHECKING	

Figure 15 Morphological matrix with designed organs to fulfil the required functions [26]

In the matrix above (shown in **Figure 15**) are stated all main functions (yellow field on the left) which are needed to create a functional and suitable product. Moreover, in the left part of the matrix (white field) are possible ways to fulfil these functions. In some cases, there are more alternatives, but it depends on the engineering designer fantasy and also on his ideas. In the background of this matrix, there are many sketches and surveys, so the best alternatives and best solutions for every single function can be found.

3.2.1.2. Conveyor positioning

The main problem for the physically disabled operator is the height of the conveyor. That is because these operators can be on the carriage or their height is unusual. It can be, of course, fixed simply by using some stand or ramp, but this solution is very uncomfortable for disabled operators, and it can also cause the injury. The better way is to allow the adjusting of the conveyor height, but it can be very complicated because of the tensioning mechanism, type of belt, cooperation with the robotic hand working in the injection moulding machine.

Angled conveyor

Angled conveyor shown in **Figure 16** is quite a useful alternative because there is not necessary to adjust the robot (because of changing height), but there is still a problem when the transported product is something small and rounded because of the slanted part of the conveyor it can start to roll down. This problem can be fixed using the shaped belt, but this type of belt is complicated to combine with an angled alternative.

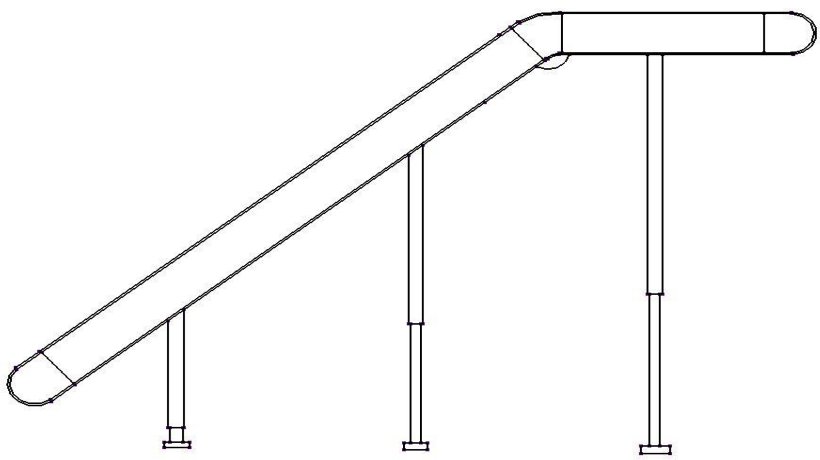


Figure 16 Angled conveyor

Sliding desk

A sliding desk is some kind of desk, which can be used to capture products falling from the conveyor and it transports them in some lower place. That means in this alternative is conveyor height fixed, and the desk itself can be adjusted. Nevertheless, this desk has to fulfil many requirements for functionality and safety.

1. There has to be some kind of covering on the desk sides to reduce the risk of injury.
2. The product which is transported by the sliding desk should not be damaged by sliding.
3. The desk has to allow the changing of heights, and potentially I should be retractable.
4. Fixation of the desk position has to be stiff enough.
5. The gap between the desk beginning and the conveyor belt has to be small enough to prevent pulling in some objects.
6. Adjusting the desk has to be safe and straightforward. (Because the operator should be able to adjust it himself/herself)
7. The conveyor should be equipped with some removal place or desk, where will slide products from the conveyor.
8. The desk must not endanger the primary function of the conveyor.

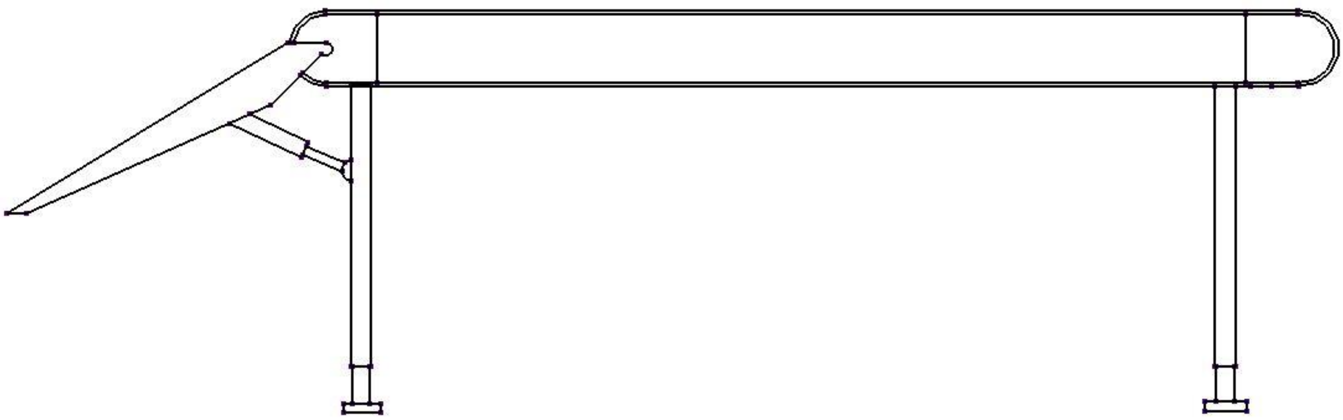


Figure 17 Sliding desk

Scissors positioning mechanism

This alternative makes a conveyor adjusted to some unique positioning mechanism, which allows adjusting its height, but one disadvantage is the problem of adjusting the dropping position for the robotic arm in the injection moulding machine.

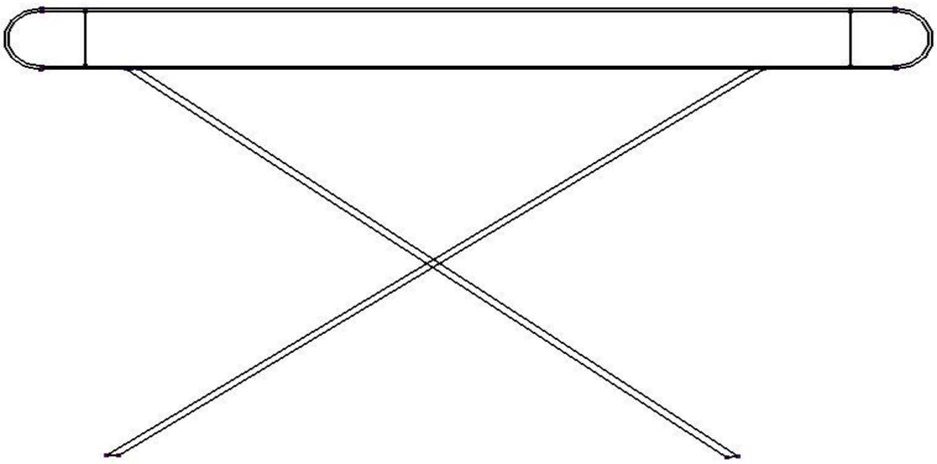


Figure 18 Scissors positioning mechanism

Alternatives of the TS organs structure

As an outcome of the engineering design thinking was created matrix showed in **Figure 19** where are highlighted three alternatives (distinguished by colours) which can be considered as final alternatives. Every alternative is connecting different ways to fulfil the functions, but in some cases, they are using two ways to fulfil the primary functions because that combination sometimes offers the best results.

Organs for the functional structure of TS								
Main function of TS and its asistating functions			Organs of TS (function bearers)					
			1	2	3	4	5	6
FUNCTION 1	1.0 To Provide the FEED		BELT	ROTATIONAL TABLE	WORM	CHAIN	V-BELT	VIBRAION DESK
	1.1 To CENTER the belt		BOMBERING	BELT WITH GUIDANCE				
	1.2 To RUN the belt		HYDRAULIC GENERATOR	ELECTRIC ENGINE	PNEUMATIC GENERAT	PETROL ENGINE		
	1.3 To SUPPORT the belt		METAL SHEET	METAL BELTS	ROLLERS			
FUNCTION 2	2.0 To TIGHT the belt		HORIZONTAL PULLEY	VERTICAL PULLEY	WEIGHT	TIGHTED ROLLER		
	2.1 To CHECK the TENSION		SENSOR					
FUNCTION 3	3.0 To TRANSPORT the product	3.1 Material of the belt	PU	PVC	MODULLAR (SPECIAL)	STEEL	TEXTILE	
		3.2 Type of the belt	SHAPED	SIMPLE				
FUNCTION 4	4.0 To secure the SAFETY	4.1 To check the POSSITION of the belt	SENCOR					
		4.2 To COVER dangerous places	COVERING LINES	TUNNEL COVER	COMBINATION	EMBEDED BELT		
		4.3 To allow quick SHUTDOWN	CENTRAL STOP BUTTON	TWO HANDS CHECK	AUDIO (VOICE) SWITCH	COMBINATION		
FUNCTION 5	5.0 To secure the ERGONOMICS	5.1 To allow ADJUSTING	SCISSOR MECHANISM	SLIDING DESK	ANGLED CONVEYOR			
		5.2 To be COMFORTABLE to use	AUTOMATICAL POSITIONING	MANUAL POSITIONING	SPECIAL MATERIAL OF COVERS	COMBINATION		
FUNCTION 6	6.1 To CONNECT conveyor with the machine		A. TYPE OF FRAME	B. TYPE OF FRAME	C. TYPE OF FRAME			
FUNCTION 7	7.0 To make it SMART		TEMPERATURE CHECKING	COOLING	POSITION CHECKING	SURFACE	WEIGHT CHECKING	

Figure 19 Alternatives of organs to fulfill the required functions
Alternative A – Blue color
Alternative B – Red color
Alternative C – Green color

Alternative A

The first (blue) alternative is based on the principle of belt conveyor it is using bombeered roller to centre the belt, and it is powered by an electrical engine that is placed inside the front roller. As support of the belt is a conveyor equipped with metal sheets which allows an effortless and very suitable way to support the belt. Tensioning and centring of the belt are enabled by a horizontal pulley and adjustable roller placed in the backside of the conveyor. Tension in the belt is checked by a sensor placed under the belt, which is made of polyvinylchloride (PVC). The shape of the belt is simple, and on the sides of the conveyor are placed two sensors. These sensors are checking the position of the belt and preventing accidents with a side of the frame. The conveyor can be in emergency shut down by an emergency stop button or by an audio sensor which allows detecting of shout caused by injuring the operator. The conveyor is attached to the injection mould machine by a unique frame. This frame is divided into two sections. First, it is the ejecting-frame which is connected to the conveyor body and the second is fixed conveyor, which is placed on supporting triangular consoles. This alternative has special equipment that consists of temperature checking, cooling, and position checking. Adjusting the height is provided by an adjustable sliding desk. This desk can be turned around the powered roller and allows sliding of product to lower position.

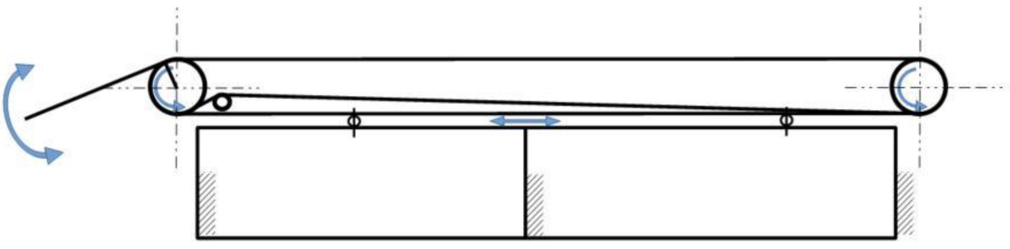


Figure 20 Conceptual design of the organ structure: Alternative A

Alternative B

The second (red) alternative is the most simple. As the other two alternatives are this alternative also based on the principle of belt conveyor but the centring of the belt is solved little bit different. The belt is equipped with a unique thong placed under the belt. It is connected to the belt all over its length. This thong is used to guide the belt on the conveyor and centre it. The engine is placed in front of the conveyor inside the front roller. To save the material the belt is supported just with metal belts, and it is also equipped with special

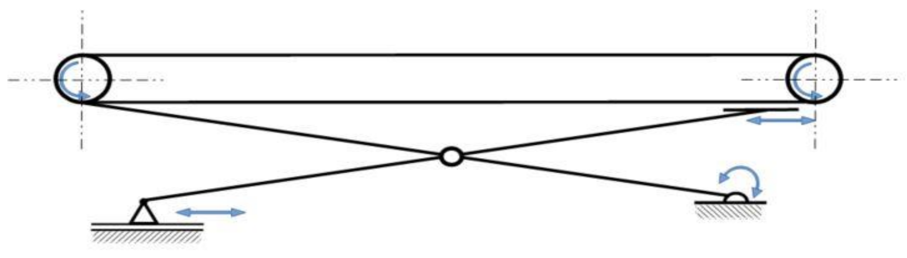


Figure 21 Conceptual design of the organ structure: Alternative B

weight which checks the mass of the product transported on the belt. This alternative uses a simply shaped textile belt. The central stop button can stop the conveyor. Adjusting of conveyor height is provided by the scissor mechanism which is manually operated.

Alternative C

The third (green) alternative is based on the principle of a conveyor belt. The positioning of the belt is enabled by bombeered rollers powered by an electrical engine that is placed inside the front roller. The belt is placed on smaller supporting rollers all over its length. The rollers can adjust the belt tension. This tension is checked by the sensor placed in the lower part of the conveyor; the belt comprises of polyurethane, and it is shaped to prevent products sliding. Corners of this belt are hidden inside the sides of the conveyor's frame. That makes the belt less dangerous for the operator or products. Conveyor allows to emergency stop using the central stop button or audio stops. The audio stop allows the machine to register shout if someone is injured. The main principle of this alternative is based on the principle of a twice angled conveyor. On the covering will be used materials that are pleasant to the touch to make it more comfortable to use. The conveyor will be manually adjustable, and it will be able to check the position of the product on the belt and check the surface of the product. Evaluating of the designed alternatives of the TS Organ structure

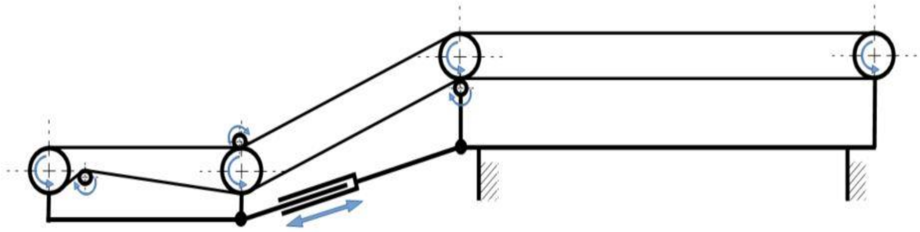


Figure 22 Conceptual design of the organ structure: Alternative C

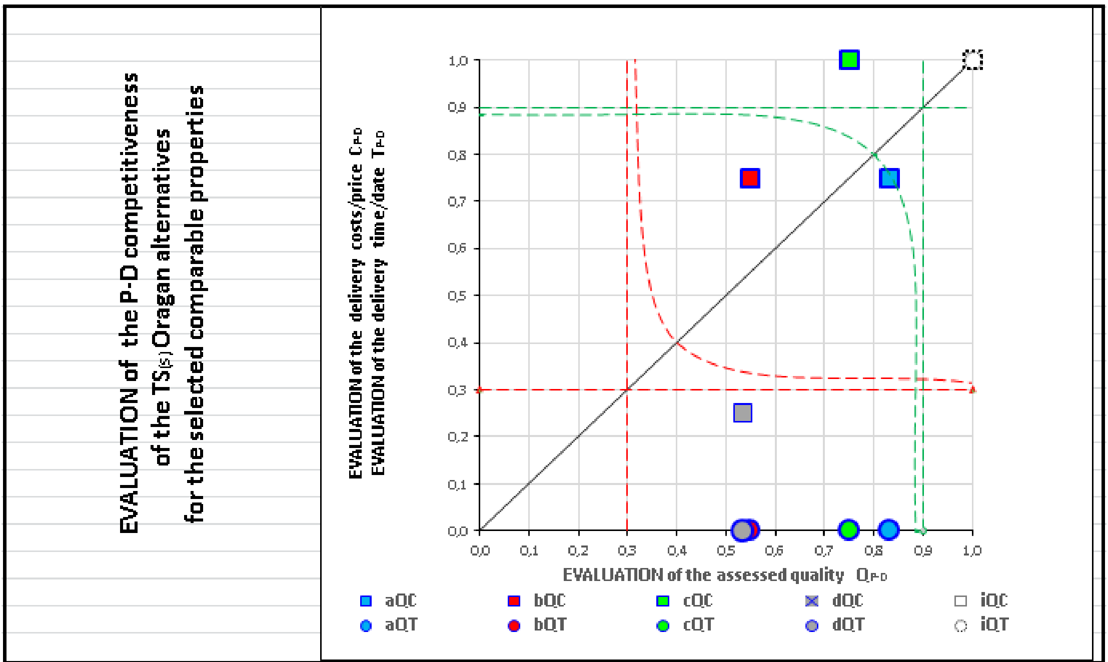
3.2.1.3. SWOT evaluation of properties and competitiveness of alternatives of TS Organ structures

To decide about the suboptimal result is necessary to evaluate selected requirements for each alternative. Of course, there is very important to evaluate it precisely and objectively, because without objective evaluation cannot be the result taken as reliable. **Figure 23** shows the evaluation of all alternatives, starting product and ideal product.

SPECIFICATION of criteria for evaluation			SWOT evaluation of alternatives					
TS(s) :	Integrated Conveyor Belt		Optional limits:	lower:	0,3	upper:	0,9	
Rating scale [VDI-2225 1977]	DIAGR. ►► Area Q^T^C	Requirement / Criterion Comparable competitive property	Alternative of TS(s) Organ structure					
			TS0	A	B	C	TS	TSi
Suitability evaluation (min. 0 ÷ max. 4)	Assesssed quality Q	To Provide the FEED	-	3	3	3	3	4
		To CENTER the belt	-	2	3	2	2	4
		To RUN the belt		3	3	3	3	4
		To SUPPORT the belt		3	2	3	3	4
		To TIGHT the belt		4	3	3	3	4
		To CHECK the tension		4	1	4	1	4
		Material of the belt	-	3	2	2	3	4
		Type of the belt	-	3	3	3	3	4
		To CHECK the position of the belt		3	1	3	1	4
		To COVER dangerous places	-	3	2	2	1	4
		To allow quick SHUTDOWN	-	4	2	4	2	4
		To allow ADJUSTING	-	4	2	2	1	4
		To be CONFORTABLE to use	-	3	2	3	2	4
		To CONNECT conveyor with the machine	-	4	2	4	4	4
		To make it SMART	-	4	2	4	0	4
		---	-	-	-	-	-	-
		∑ suitability evaluation Q	-	50	33	45	32	60
		∑ standardized evaluation Q (0 ÷ 1)	-	0,83	0,55	0,75	0,53	1,00
	Delivery time/date T	Total delivery time - identical	-	-	-	-	-	4
		---	-	-	-	-	-	-
		---	-	-	-	-	-	-
		∑ suitability evaluation T	-	-	-	-	-	4
		∑ standardized evaluation T (0 ÷ 1)	-	0,00	0,00	0,00	0,00	1,00
	Delivery cost/price C	Total delivery costs	3	3	3	4	1	4
		---	-	-	-	-	-	-
		---	-	-	-	-	-	-
		∑ suitability evaluation C	3	3	3	4	1	4
		∑ standardized evaluation C (0 ÷ 1)	0,75	0,75	0,75	1,00	0,25	1,00

Figure 23 Requir. / criteria specification for the selected key P-D properties of TS Organ structure and SWOT evaluation of the designed alternatives [26]

The best way to show the results transparently is by charts. The chart showed in **Figure 24** displays the graphical results from the previous **Figure 23**. It shows that the alternative A reaches high quality for (relatively) low price. As is shown in **Figure 24**, alternative C is the best solution from the costs perspective, but in this will be the final decision based on the quality perspective. That makes the alternative A the most suitable alternative from the quality perspective (best combinations of ways to fulfil the functions).



Back to Criteria specif. & SWOT evaluation :	◄◄ Criteria SPECIFICATION & SWOT evaluation of alternatives		
Requirements to the Q*T*C area:	Q P-D PRODUCT-DESIGN ("engineering design") TS(i) CONTRACT QUALITY	T P-D PRODUCT-DESIGN ("engineering design") TS(i) CONTRACT TIME / DATE	C P-D PRODUCT-DESIGN ("engineering design") TS(i) CONTRACT COST / PRICE
TS Life cycle stage :	Operation	Operation	Operation
Weight of properties / requirements (0 - 4) :	4	4	4
Results of the weighted SWOT evaluation (0 - 1): Starting TS0 Org. struct.	0,00	0,00	0,75
Alternative TS Org.struct. a	0,83	0,00	0,75
Alternative TS Org.struct. b	0,55	0,00	0,75
Alternative TS Org.struct. c	0,75	0,00	1,00
Alternative TS Org.struct. d	0,53	0,00	0,25
Ideal TSi Org. struct.	1,00	1,00	1,00

Figure 24 Result of the SWOT evaluation of the P-D properties of the designed alternatives of TS Organ structure to compare their P-D competitiveness [26]

3.2.1.4. Strengths and Weaknesses

As a part of the decision process on the most suitable alternative, the list of strong and weak properties is also considered. This list (or in this case table) contains strong, weak and risk properties of all three alternatives, for better clarity, individual alternatives are highlighted with their colour.

Alterantives of TS organ structure:	A	B	C
Order by systematic evaluation	1.	3.	2.
S - ADVANTAGES - strong sites/properties	Centring is quite effective	Fixed guidenance	Very complex solution
	Provide of good support of belt	Safe of material on metal belts	Very flexible possitioning
	Combination of tunnel and covering lines offers high	Allows to measure weight	Integrated covering reduces costs
	Positioning mechanism is quite simple and cheap	Adjustable in quite hing range	Sensoring makes conveyor flexible to use
	Sensoring equipmnet allows to cool the products	………………………	Allows quick shutdown which impoves safety
	Audio central stop offers more safety	………………………	………………………
W - DISADVANTAGES - weak sites/properties	Use of bombeering will rise the price	Low level of smart equipment	High costs
	………………………	Very difficult to reconciliation of the	Difficult assembly
	………………………	………………………	Heavy
	………………………	………………………	………………………
R - RISKS - risk sites/properties	Air cooling in tunnel can be dusty	Textile belt can be easily damaged	Danger of stucking of belt
	Mechanism used to tight the belt is not proof	………………………	Difficult ejecting out of workspace
	Use of sliding desk can cause problems with	………………………	………………………

Figure 25 Strengths and Weaknesses of each alternative [26]

Alternative A was selected as the most suitable because the evaluation of the reached quality showed that this alternative is most suitable. This alternative was a little bit weaker in the price, but because the number of its weaknesses is very low, it was selected as the most suitable alternative, and the following work will be focused on this alternative.

4. CONSTRUCTIONAL ENGINEERING DESIGN

In spite of the fact that it is not enough to create just the 2D conceptual design of the designed product, a full constructional 3D design of the product will be created in this chapter. The most important and most complicated and problematic components of the conveyor assembly (from constructional perspective) will be introduced, and there will be mentioned most crucial information about them to offer the most detailed understanding of its functions and properties. At the end of this chapter are published some calculations and FEM analysis, which demonstrates the load of some (most loaded) parts.

4.1. Engineering design of the rough TS Constructional structure

4.1.1. Drive selection

The first step in the whole constructional design was to answer the question "How the conveyor will be powered". The standard for injection moulding machine is that the conveyor is powered from socket placed under the machine (but of course could be solved differently) but there is the other question "How to place the engine to spent layout place" because there is very small layout place on sides of conveyor to place the engine there. Due to that were explored possible ways to place the engine.

1. Engine on sides of the conveyor
2. Engine under the conveyor
3. Engine inside the powered roller

In the first two cases occurred problem with the layout place. First "engine on the side" needs much space, and that means that the engine cannot be placed on the left side (the side where is the moulding machine placed), it could be placed on the right side, but that is not very suitable from safety, ergonomic and visual perspective. The second idea "engine under conveyor" seemed wrong because the conveyor should be able to be pulled out of the moulding machine workspace (due to maintenance) and engine under the powered roller can block this movement. The last idea "engine inside" was selected as an ideal solution because the layout place is not built-up and it means "No complex shapes" from the visual point of view and also "Reduce of rotating parts" (the connection between engine and roller) from the safety point of view. There is also one disadvantage the price can be higher and also the maintenance can be more complicated.

Figure 26 Engine placed under the conveyor [7]

Figure 27 Engine inside the roller [9]

Figure 28 Engine on the side of the conveyor [8]

4.1.2. Drive holder

The next step was to solve "How the drive will be attached to the construction", it was necessary to create some kind of holder which allows easy and reliable mounting to the powered roller. The powered roller is placed in the front of the conveyor. Because of the maintenance and manufacturing will be the mainframe assembled from aluminium Bosch profiles, due to that should be all parts easily connectable to these profiles. There will also be the next difficulty, to magnify the bending angle of the belt around the powered roller will be used another adjusting roller, which will allow adjusting of the wrap angle and also will help to centre the belt more precisely and more quickly.

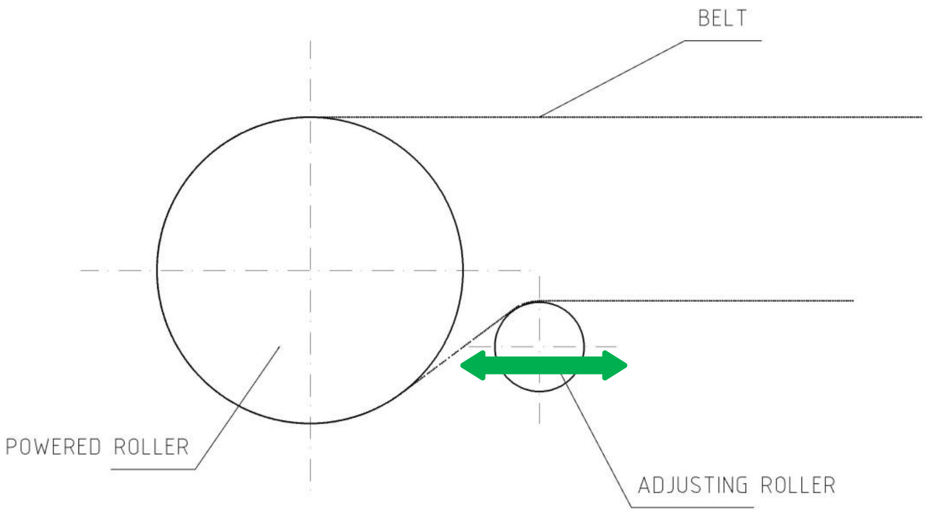


Figure 29 Scheme of powered and adjusting rollers

Adjusting roller should be moveable in a horizontal direction, due to spending of place. There arises a new question "How to adjust the adjustable roller", ideal solution for this application is to adjust the roller by a bolt. This bolt must be accessible from the front side of the conveyor to adjust it without pulling out the conveyor from the machine workspace.

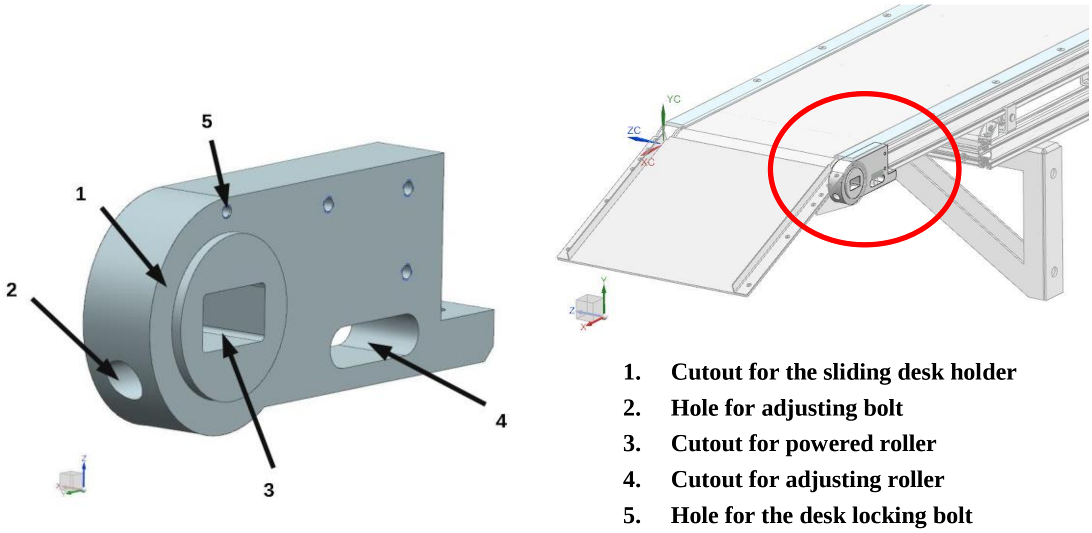


Figure 30 Front roller holder (rough design)

In **Figure 30**, the front roller holder is shown, which carries powered roller and adjusting roller. This component is made of aluminium alloy (to be easily manufactured and spend the mass). The front hole for the bolt offers easy access to tight the adjustable roller.

4.1.3. Sliding desk

The sliding desk is placed in the front part of the conveyor. It enables sliding overflow of the product from belt to lower place (for example, on special positioning table). This desk is placed on two holders which are attached to the powered roller holders (special cutout). This desk will enable a disabled operator to remove products from the conveyor in adjustable height and also slow sliding of product into some storage place (when the operator is not able to keep up with the conveyor). That will enable a very ergonomic working environment for the disabled operator.

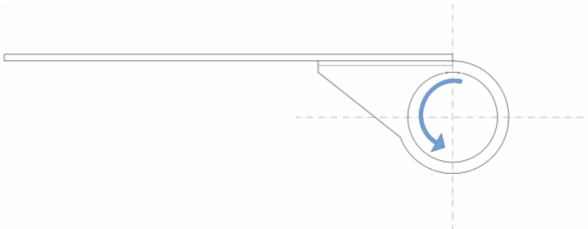


Figure 31 Sliding desk with desk holder

Figure 31 shows the rough idea of the sliding desk. The blue arrow shows the direction of the adjustable angle. The sliding desk is the primary component which offers an ergonomic and user-friendly environment for the disabled operator.

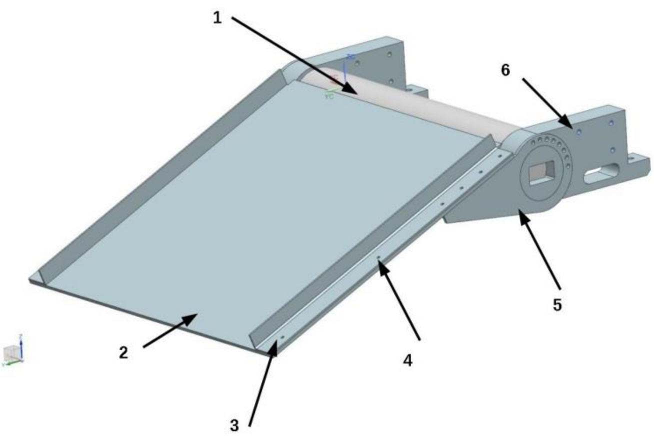


Figure 32 Sliding desk (rough design)

1. **Powered roller**
2. **Desk**
3. **Side ledge (protects product against falling on sides)**
4. **Holes for bolts**
5. **Desk holders (thanks to holes inside these holders is enabled positioning of the desk)**
6. **Powered roller holder**

Figure 32 displays the rough construction of the conveyor's sliding desk. This construction allows access to the adjusting bolt when the desk is folded down. On sides of the desk will be used bolts with the user-friendly shaped head (because the usual shape is not suitable for this application). The lower side of this desk (see **Figure 33**) is specially shaped (in the place where the belt is nearest to the desk) to prevent dangerous collisions with the belt because the product can be stuck in the vacation between the belt and the desk.

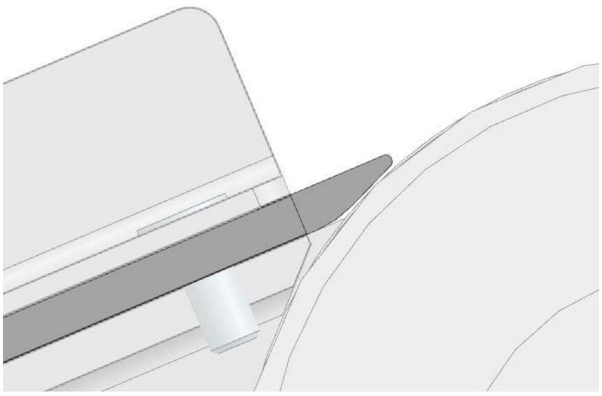


Figure 33 Shape of the desk on belt´s side

4.1.4. Adjusting roller

Adjusting roller (shown in **Figure 34**) is part of the conveyor, which allows changing of belt's wrap angle, changing tension in the belt, and also belt adjustment (if the belt is moving out of its centre). This roller (cylinder-shaped) is made of steel, and it is mounted on two roller bearings. Because of the expectation of a clean environment without dust and high humidity, there will be used covered bearings. Bearings are mounted on the simple shaft, and they are fixed by retaining rings. On sides of this shaft are parallel threaded holes. These holes allow adjusting the shaft by tensioning bolts.

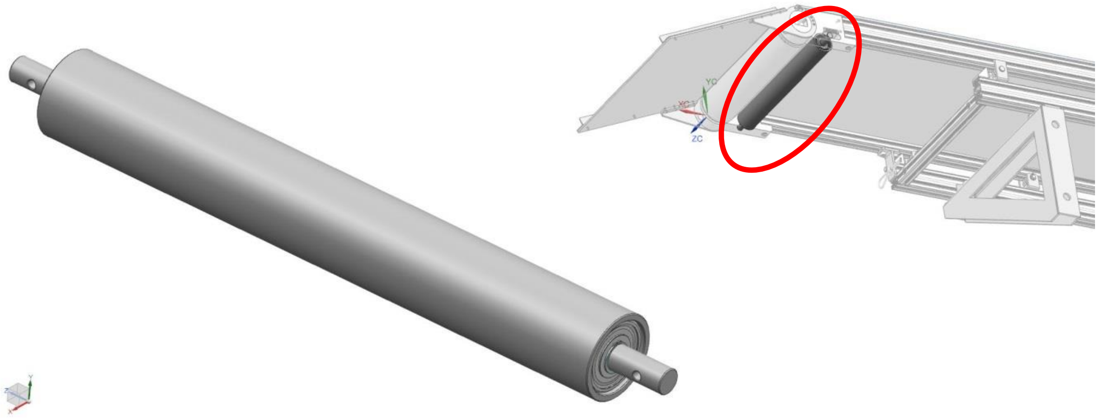
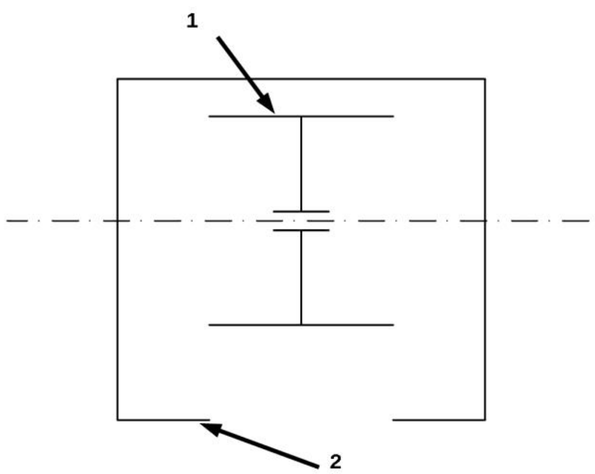


Figure 34 Adjusting roller

4.1.5. Pull out rollers

The starting product from Engel has a straightforward solution of conveyor pulling out system, but this solution is not so effective because there are problems due to high friction between its parts. For disabled operator can be a problem to pull the conveyor out of the injection moulding machine workspace when there is high friction and due to that high resistance. So at this point, there was one crucial question "How to make the pulling system simple and effective".

The first constructional design thinking was to replace sliding contact by rolling contact. That can reduce most of the resistance against pulling the conveyor out of the workspace and also it will reduce the wear of pulling out systems. The next problem was to avoid falling off the upper part of the frame from the lower part of the frame during the pulling movement.

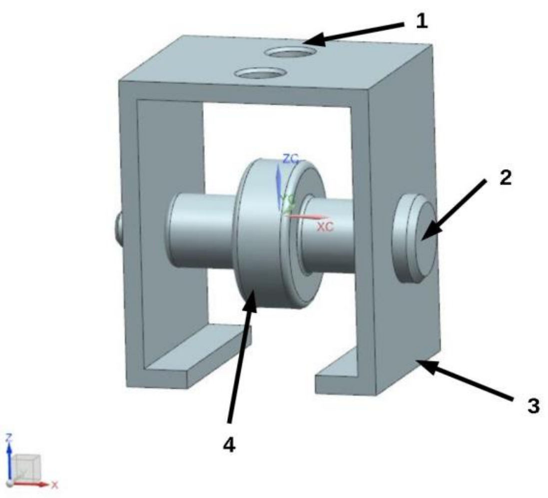


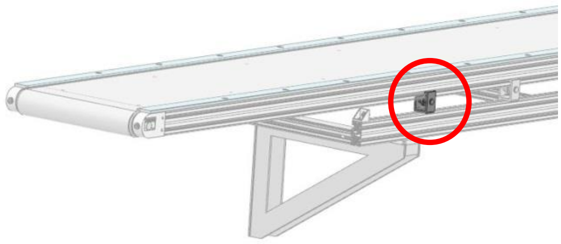
1. **Roller**
2. **Holder**

Figure 35 First thinking about „pulling out“ system

Figure 35 shows the first idea about this rolling system used to pull the conveyor out. There are two main parts. The roller is the rotary part which is in contact with the surface of the upper frame. The holder is the specially shaped metal sheet which is designed to avoid falling off the lower part, and it is attached to the lower part.

This rolling system is useable just for frames made from Bosch profiles because parts (rotary and shaped metal sheet) are adapted for it. The shape of the rotary part avoids going to the side, and the sheet metal avoids falling off the lower part and also offers an easy way to adjust the upper frame by simple bolt attached to the lower frame from the side.





1. **Holes for attachment the roller to lower part of the conveyor**
2. **Pin carrying the rotary part**
3. **Shaped metal sheet adapted to Bosch profiles**
4. **Rotary part shaped and adapted to Bosch profiles**

Figure 36 Roller system to pull out the conveyor (rough design)

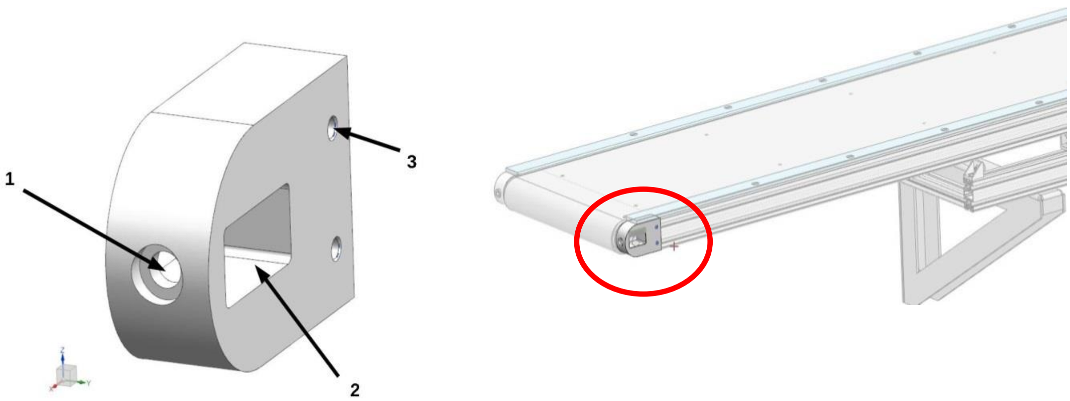
4.1.6. Back roller

The purpose of the back roller is to adjust tension in the belt and also rough centring of the belt. Its construction is mostly the same as in the adjusting roller. There is a main steel roller coat mounted on two roller bearings, which are mounted to simple shaft and fixes by retaining rings to it. Threaded holes located on the shaft sides enable moving the shaft to adjust the tension and to centre the belt. As was mentioned before, the construction of this roller is very similar to the adjusting roller.

Figure 37 Back roller assembly (rough design)

4.1.7. Back roller holder

This part is carrying and mounting back roller, and it also has to allow adjusting of this roller. A back roller holder is made of aluminium alloy, and there is no need for the shape because of the visual perspective because this part of the conveyor is placed in the injection moulding machine, so it is not the main part for the visual effect of the whole product.



1. **Front hole for bolt, to enable adjusting of the roller**
2. **Cutout for back roller´s shaft**
3. **Threaded holes for locking bolts**

Figure 38 Back roller holder (rough design)

4.1.8. Upper frame

One of the fundamental issues concerning the supporting structure is "Which type of construction should be used?". There can be used welded construction, screwed construction, rivet construction. From these types of construction was selected screwed construction based on aluminium Bosch profiles, because this type of construction offers the easiest composition and maintenance. The primary function of this part of the conveyor is to support the belt using a sliding desk, to connect all parts of the conveyor, and carry the main load caused by the mass of conveyor and mass of the product. This frame is connected to the pull out rollers, due to that whole upper frame able to be pulled out. The upper part of the conveyor's frame was created using MAY-CAD from company MayTec. This program is using profiles, and parts offer from company MayTec, and it is very user friendly.

Figure 39 shows the upper frame, and from this view, it is evident that this frame is very simple and very space-saving and that is an essential aspect because the construction of this conveyor should not be too massive.

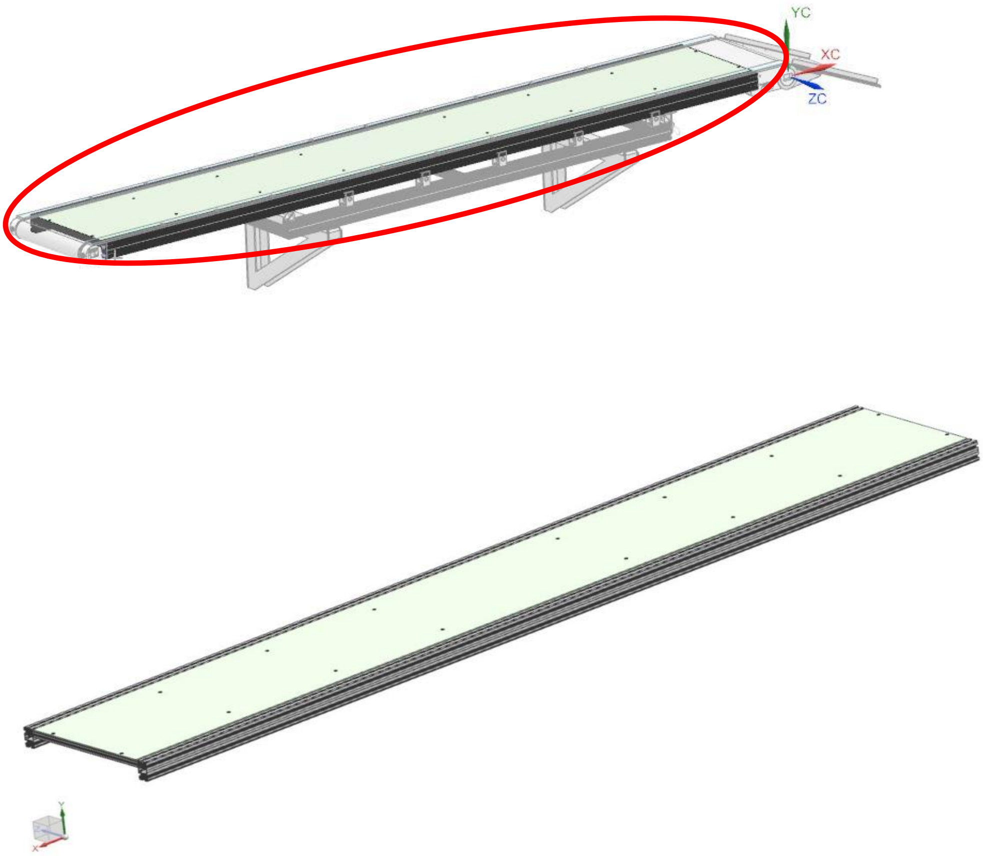


Figure 39 Upper frame

4.1.9. Lower frame

The upper frame is connected to this part of the conveyor using the pull out rollers and load on the upper frame is transferred on this lower frame. There was one difficulty to solve that was to enable pulling out the conveyor because the pull out rollers need to its function free side of the aluminium profile.

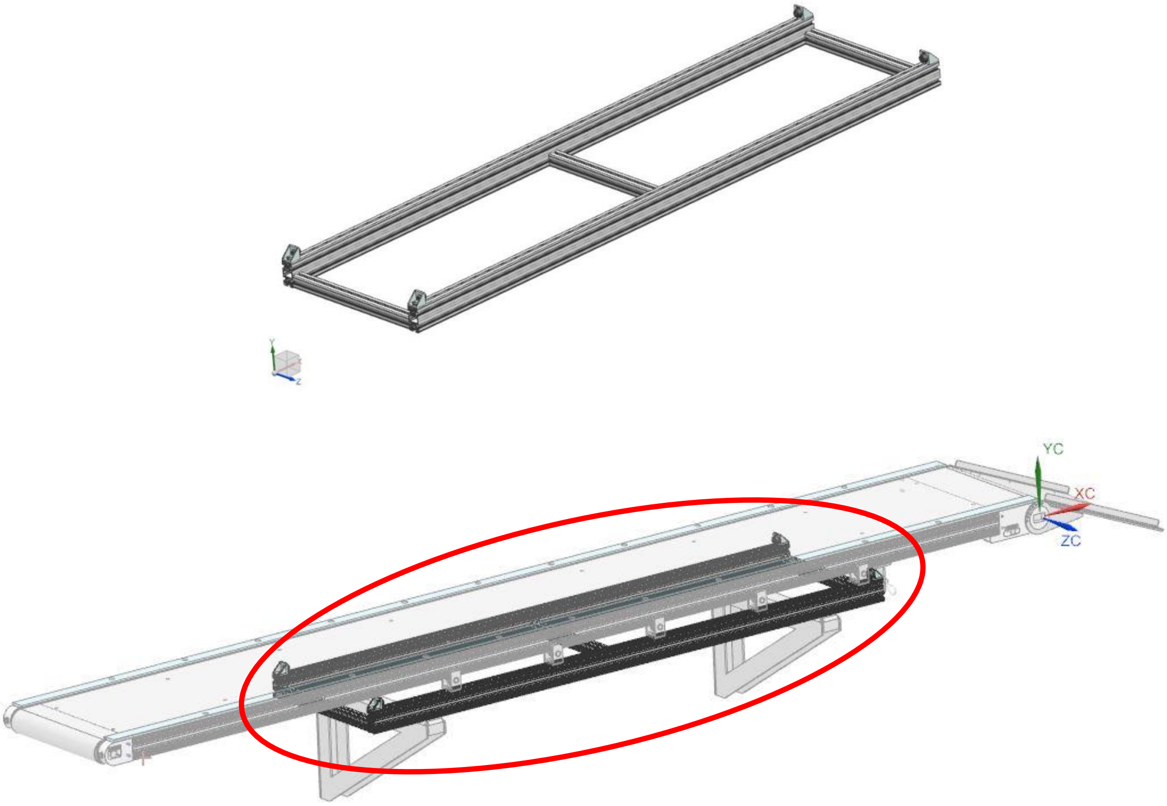
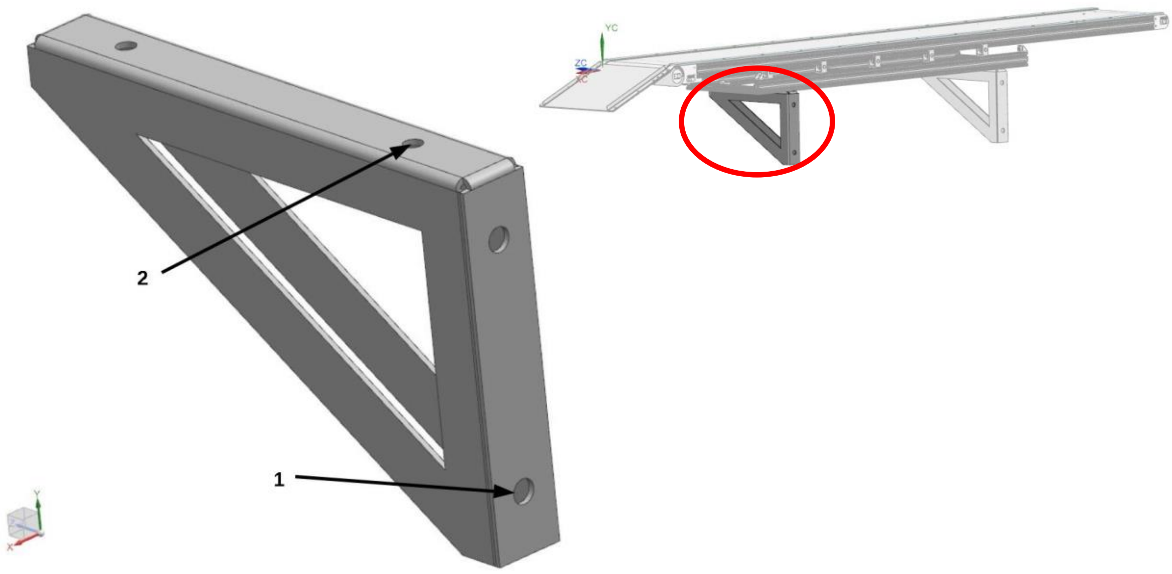


Figure 40 Lower frame

In **Figure 40** is displayed lower frame of the conveyor. Its construction is based on the same principle as the upper frame and in corners are placed rubber stoppers, which are designed to stop the conveyor in edge positions.

4.1.10. Supporting consoles

To attach the whole assembly of the belt conveyor to the injection moulding machine are used two triangular consoles (shown in **Figure 41**).
These consoles are made of metal sheets and in the corners (where are the in contact two corners) are welded. Consoles are made of the steel EN 10025 (ČSN 11 373) which is suitable for metal sheet constructions. Because in Engel company are very well equipped for manufacturing of metal sheet, there will be no problem to create this part of the conveyor, which can be challenging to manufacture.



1. **Two holes for attachment to the injection molding machine (Ø 20 mm).**
2. **Two holes for attachments of the lower frame to the consoles (Ø 16 mm)**

Figure 41 Supporting consoles

4.1.11. Lock

Because the sliding friction between the upper and lower part of the conveyor was reduced and replaced with rolling resistance arises the higher danger of spontaneous travelling of conveyors upper part out of the injection moulding machine workspace. Due to that is designed construction of a conveyor equipped with the lock which will prevent this spontaneous movement.

This lock is assembled from three main parts, as is shown in the picture below.

1) Lock body

This part is manufactured from the metal sheet created of steel EN 10025 (ČSN 11 373). The lock body is made of two metal parts welded together and equipped with three holes. Two holes in the upper part are used to attach the lock to the upper frame (to the bottom). To this connection are used two bolts M8 and two connectors, placed in the profile groove. The last hole (Ø 14 mm) is for locking pin.

2) Locking bolt

The locking bolt is specially shaped component attached in the front of the lower frame (in the front of the profile a thread is created) and equipped with one hole (Ø 5 mm) used to inserting a locking pin. This component is made of steel EN 10025 (ČSN 11 500).

3) Locking pin

The locking pin is a component made of bent wire (steel EN 10025 (ČSN 11 500)).

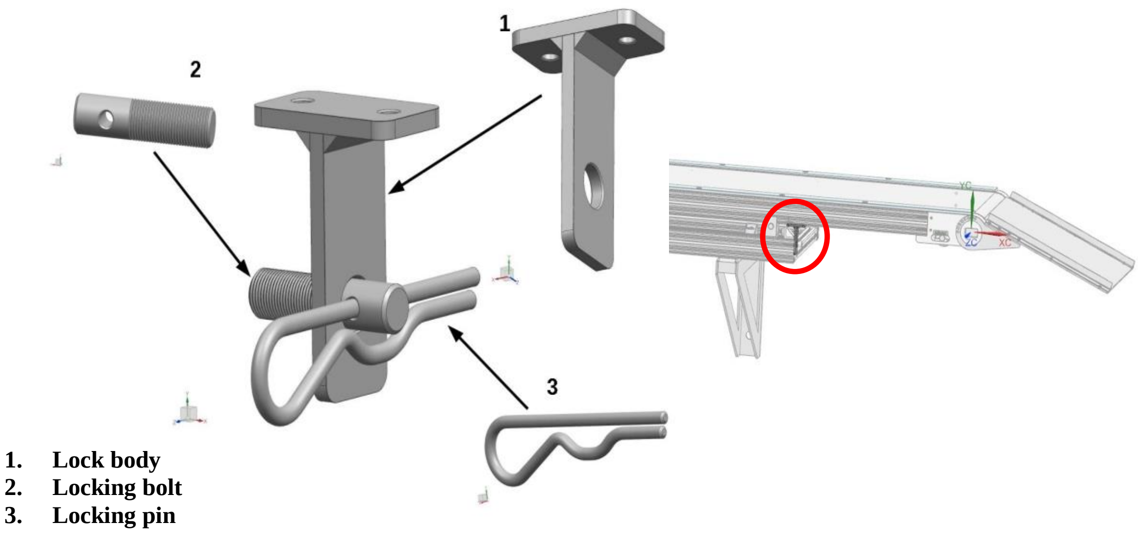


Figure 42 Lock assembly and its components

4.1.12. Conveyor belt

The width of the belt is 350 mm, and that is not a typical dimension for belts made of PVC. The selected belt "GS220/R" is form company GUMEX.

GS220/R – PVC Conveyor belt	
Maximal width	3000 mm
Operating temperature	-10°C /+80°C
Thickness of covering PVC layer	0,7 mm
Thickness	2,4 mm
Count of inserts	2

Figure 43 Basic information about conveyor belt [11]

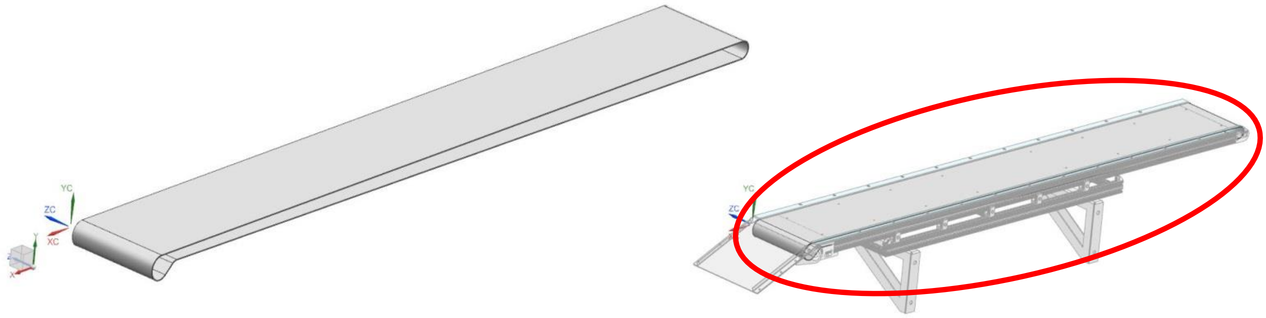


Figure 44 Conveyor belt

4.1.13. Adjustment system

Adjusting and centring of the belt on the conveyor is a very common and necessary part of the maintenance. However, it is complicated to make it repeatable. The problem with wrong centring of the belt can be caused by:

- wrong belt connection
- wrong assembly of the conveyor
- asymmetrical belt load

To make the centring more easy and repeatable was the conveyor equipped with measuring plates. On these plates are highlighted millimetre distances and the plates are glued to the roller holders. From these plates can the maintenance worker easily deduct and write down the position of shafts sides for next adjusting.

As was mentioned, these plates are placed on the front and back roller holders (see **Figure 45** and **46**) above adjusting cutout for the shaft of the roller. For more comfortable adjusting should be the sides of a shaft equipped with the making line in the centre.

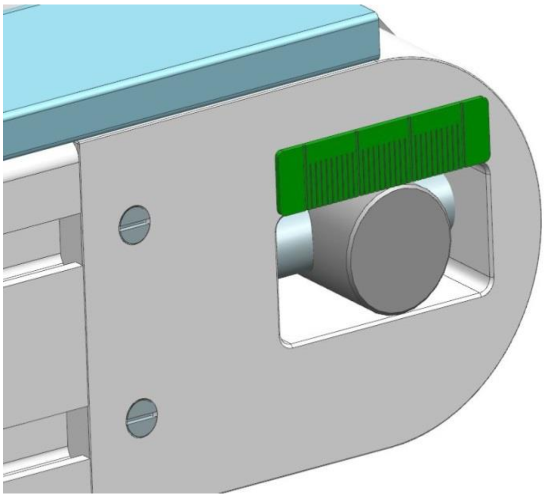


Figure 45 Back holder with the measuring plate

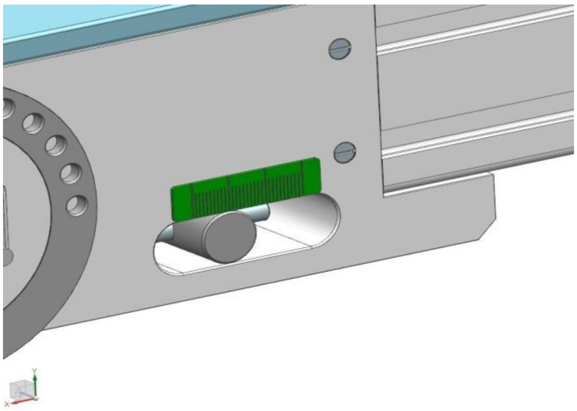


Figure 46 Front holder with measuring plate

4.1.14. "SMART" components.

A. Checking of belt position

The first needed equipment of the conveyor is two-position switches. The purpose of these two switches is to check the position of the belt, and if the centring of the belt is poorly executed, the belt will turn one of these switches on and the conveyor will be turned off. Then should be the belt checked and adjusted and centred more precisely to avoid the next shutdown of the conveyor. The location of these sensors will be adapted to the customer requirements because it will depend on customer needs and preferences. For these sensors will be created unique cutout in the upper frame (on its side) and the next cutout inside the covering lines (of course can be adapted to customer needs). Due to that will be the sensor hidden under the covering line, and the danger of the incorrect shutdown (caused by touching this sensor by the product) will be prevented.

Selected position switch is **Schneider Electric XEP4E1W7A326** (showed in **Figure 47**).

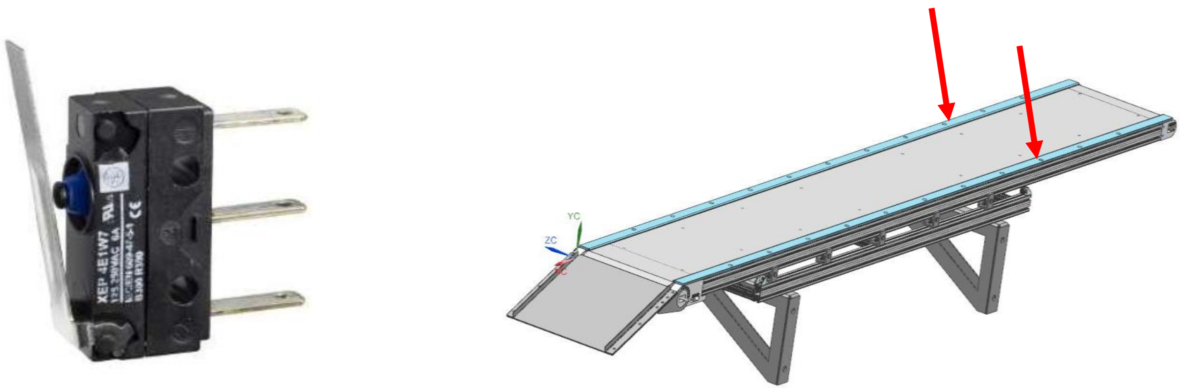


Figure 47 XEP4E1W7A326 [22]

B. Checking of belt tension

For checking of tension in the belt was selected similar position switch, which will be mounted (also based on the customer needs and preferences) to the sensor holder that will be attached to the traverse struts of the upper frame (bottom part). This sensor will be adjusted to be permanently closed by the belt, and if there will be any difference caused by sagging of the belt, this sensor will be turned off, and the whole conveyor will be turned off.

Selected position switch to check the tension of the belt is **Schneider Electric XEP4E1W7A454** (showed in **Figure 48**).

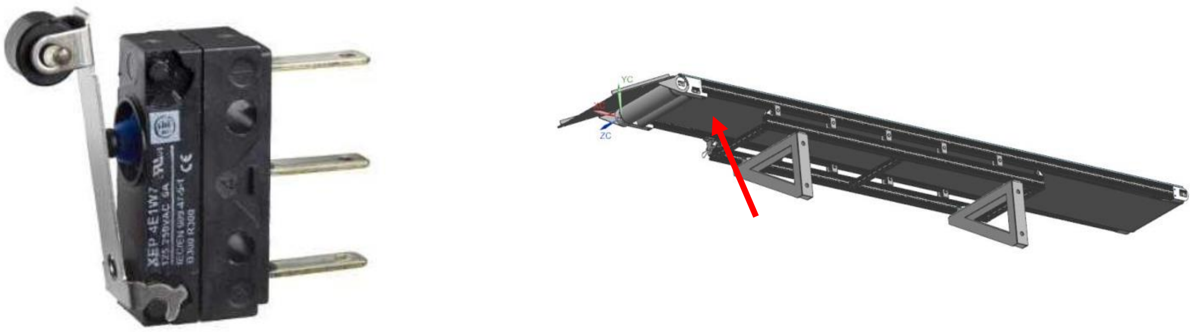


Figure 48 XEP4E1W7A454 [23]

C. Checking of position of the transported product on the belt

In the routine use of these conveyors is the problem of removing products from the conveyor. If the product cannot be dropped from the conveyor into the storage box or the manufacturing of the product has a long duration, the products have to stay on the belt until the operator removes them. Usually are caused long downtimes and complication because the injection moulding machine should not stop when the conveyor is full. Due to this will be designed product equipped with the position checking sensor. This sensor will be placed inside the covering tunnel (due to missing industrial design perspective is the covering tunnel not a part of this document), and it will capture the object moving on the belt surface. Then will be started the calculation of products placed on the belt and when the conveyor is mostly full, the operator will be called by the beam and audio warning.

Selected position checking sensor is **SOOE-RS-L-PNLK-T** from company FESTO (showed in **Figure 49**).

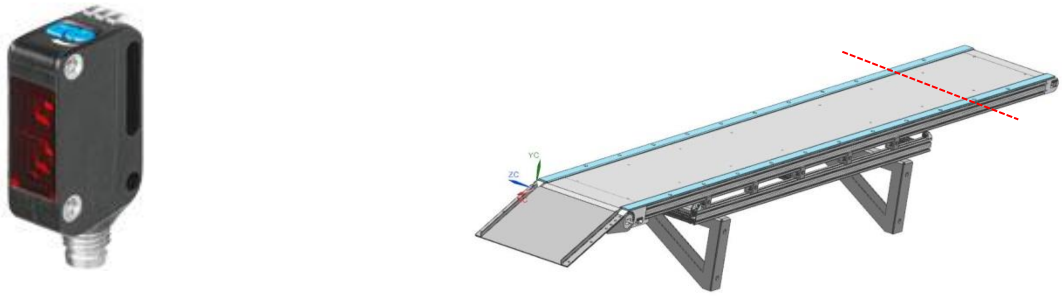


Figure 49 SOOE-RS-L-PNLK-T [24]

D. Cooling the product on the conveyor

Product dropped on the conveyor from the injection moulding machine has usually higher temperature. If the product is not cooled down during the transporting process on the belt, it can cause some troubles. Firstly, the operator can be burned by this product (if the operator removes the product). Secondly, if the product falls from the conveyor into the box, it can be damaged because the plastic material can be deformed when the products have a higher temperature. Due to this, the conveyor will be equipped with two fans. These fans will be placed in the covering tunnel (covering the conveyor for almost all of its length). Exact placement will depend on the industrial designer because at the location of the fans will be the wall of the tunnel carved to enable air intake from outside of the tunnel.

Selected fans are **SUNON A2123HBT.GN** (showed in **Figure 50**).

Figure 50 SUNON A2123HBT.GN [25]

E. Checking of product temperature

Because the checking of temperature in the range of low temperatures is a quite complicated and expensive process, this product will not be equipped with this equipment. It can be solved if there is a demand for it.

4.2. Evaluating the rough TS constructional structure

4.2.1. Prediction of properties of the rough TS Constructional structure

4.2.1.1. Calculation of drive power

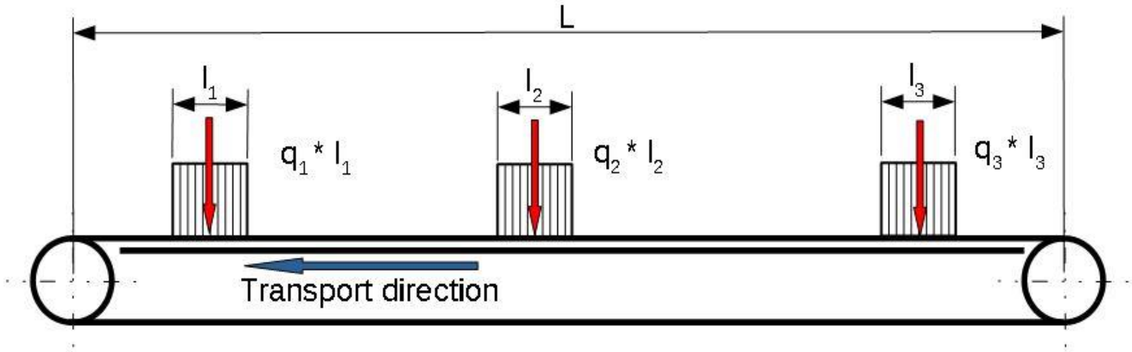


Figure 51 Calculation scheme

Firstly it is necessary to define needed values.

Needed input values:

$m := 15\ kg$	Mass of transported products [kg] m1=m2=m3=m
$f := 0.6$	Friction coefficient for contact of PVC and steel [-]
$q_1 \quad q_2 \quad q_3$	Heaviness of transported products [N/m]
q_D	Heaviness of the belt in upper part of conveyor [N/m]
$L := 2.900\ m$	Lenght of conveyor [mm]
$l_1 := 0.300\ m$	Lenght of first transported product [mm]
$l_2 := l_1 = 0.3\ m$	Lenght of second transported product [mm]
$l_3 := l_1 = 0.3\ m$	Lenght of third transported product [mm]
$g := 9.823\ \frac{m}{s^2}$	Gravitational acceleration [N/kg]
$m_b := 2.710\ \frac{kg}{m^2}$	Mass of the belt [kg/m^2]
$B := 0.35\ m$	Width of the belt [m]

$m_1 := m = 15\ kg$
$m_2 := m_1 = 15\ kg$
$m_3 := m_2 = 15\ kg$

In calculation was assumed that in the worst case (the hardest overload of the conveyor) is when there are three objects of maximal heaviness and dimensions transported by the conveyor in one moment. It is necessary to consider that there is also the mass of the belt in the upper part.

Calculations of continuous loads q1, q2, q3 and qD:

$$q_1 := \frac{m_1 \cdot g}{l_1} = 491.15 \ \frac{N}{m}$$

$$q_2 := q_1 = 491.15 \ \frac{N}{m}$$

$$q_3 := q_2 = 491.15 \ \frac{N}{m}$$

$$q_D := m_b \cdot g \cdot B = 9.317 \ \frac{N}{m}$$

Calculation of perimeter force:

$$F_0 := f \cdot L \cdot q_D + f \cdot (l_1 \cdot q_1 + l_2 \cdot q_2 + l_3 \cdot q_3) = 281.433 \ N$$

Calculation of power input (P):

Needed input values:

$v := 0.15 \ \frac{m}{s}$ Speed of the belt [m/s]

$\eta_c := 0.98$ As efficiency of the transfer was selected 98%

$$P := F_0 \cdot v \cdot \eta_c = 0.041 \ kW$$

There is no 1-phase motor in the Interroll market offer, due to that, we will use the nearest model with higher power input P = 0,075 [kW].

Specified engine, which was selected as a final solution to run the conveyor is **INTERROLL DRUM MOTOR 80S 362L** (362 mm of length) the same one as is used in the starting product from Engel. This engine is equipped with a conical riser which centres the belt and reduces sliding on sides when the conveyor is used.

Rated power (P_N)	0,075	[kW]
1-phase motor		
Gear ratio (i)	78,55	[-]
Rated velocity of the shell (v)	0,149	[m/s]
Rated revolutions (n_A)	35	[min^{-1}]

Figure 52 Drum motor 80S basic information

Company Engel provided a 3D model of this engine, and it was used in the final assembly.

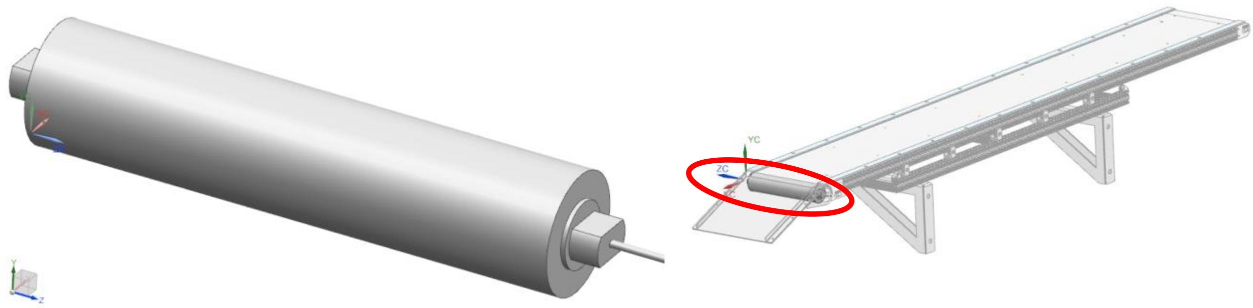


Figure 53 3D model of DRUM MOTOR 80S 362L

4.2.1.2. Conveyor assembly FEM analysis

Because using the 3D model of a designed conveyor can cause many troubles and will be very time and capacity consuming will be used idealised part. In this part were deleted some parts of the conveyor, and the construction of the conveyor was simplified. The worst problem was what to do with the Bosch profiles used in the frame construction because the meshing of these parts is quite complicated. Due to that selected hollow profiles replaced these parts, and because these parts are mostly loaded on bending, there were calculated differences between individual quadratic bending modules to recalculate the simulation results to real results.

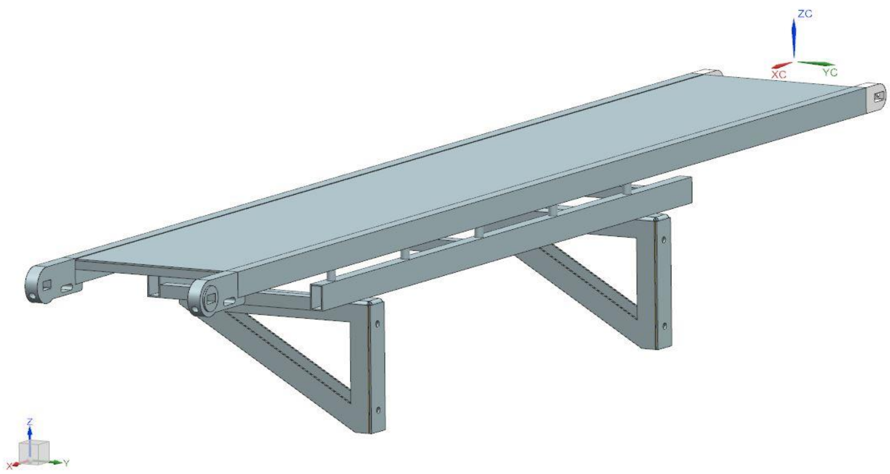


Figure 54 Idealised part of the conveyor

As is shown in **Figure 54**, there were removed parts like rollers, bolts, belt, and other smaller parts. The rest of the used parts are important because they are the most stressed parts of the conveyor. All of the ejecting rollers were replaced by standard supporting elements (of defined shape) and from this element will be calculated maximal load on the ejecting roller.

The next step was to create meshes on these parts and define their properties.

Lower frame cross-members	
Selected options	
Type of the mesh:	3D Tetrahedral Mesh
Type of the element:	CTETRA(10)
Size of the element:	13
Material:	Aluminum_2014

Figure 55 Lower frame cross-members (mesh properties)

Frame side profiles (30x60)	
Selected options	
Type of the mesh:	3D Tetrahedral Mesh
Type of the element:	CTETRA(10)
Size of the element:	20
Material:	Aluminum_2014

Figure 56 Frame side profiles (mesh properties)

Back roller holders	
Selected options	
Type of the mesh:	3D Tetrahedral Mesh
Type of the element:	CTETRA(10)
Size of the element:	12
Material:	Aluminum_2014

Figure 57 Back roller holder (mesh properties)

Front roller holders	
Selected options	
Type of the mesh:	3D Tetrahedral Mesh
Type of the element:	CTETRA(10)
Size of the element:	15
Material:	Aluminum_2014

Figure 58 Front roller holders (mesh properties)

Supporting consoles	
Selected options	
Type of the mesh:	3D Tetrahedral Mesh
Type of the element:	CTETRA(10)
Size of the element:	9
Material:	Steel

Figure 59 Supporting consoles (mesh properties)

Elements replacing the ejecting rollers	
Selected options	
Type of the mesh:	3D Tetrahedral Mesh
Type of the element:	CTETRA(10)
Size of the element:	9
Material:	Aluminum_2014

Figure 60 Elements replacing the ejecting rollers (mesh properties)

Upper frame cross-members	
Selected options	
Type of the mesh:	3D Tetrahedral Mesh
Type of the element:	CTETRA(10)
Size of the element:	13
Material:	Aluminum_2014

Figure 61 Upper frame cross-members (mesh properties)

Sliding desk of the conveyor	
Selected options	
Type of the mesh:	3D Swept Mesh
Type of the element:	CHEXA(20)
Size of the element:	12
Material:	Aluminum_2014

Figure 62 Sliding desk of the conveyor (mesh properties)

Figure 63 shows the FEM meshed model. All of the roller holders were attached to the frame using a bolt connection (1D beam) of circular cross-section with a diameter of 15 mm. Other connections were solved using the function "Mesh Mating".

Figure 63 FEM meshed part

This meshed model was loaded with its mass with the functions of "Gravity Load". Then was used the function "Force Load" to replace the mass of rollers and the sliding desk assembly in the front part (F1), in the back part (F2). The whole length of the conveyor was loaded by force (F3) this force was created to simulate the worst case of the load which can exist, that means maximally loaded conveyor by products of maxima dimensions and mass.

Forces applied on the conveyor	
Selected options	
F1	150 N
F2	25 N
F3	450 N

Figure 64 Loads applied on the conveyor

The conveyor was attached to the imaginary injection moulding machine by function "Fixed Constraint" this constrain was placed into holes inside supporting consoles.

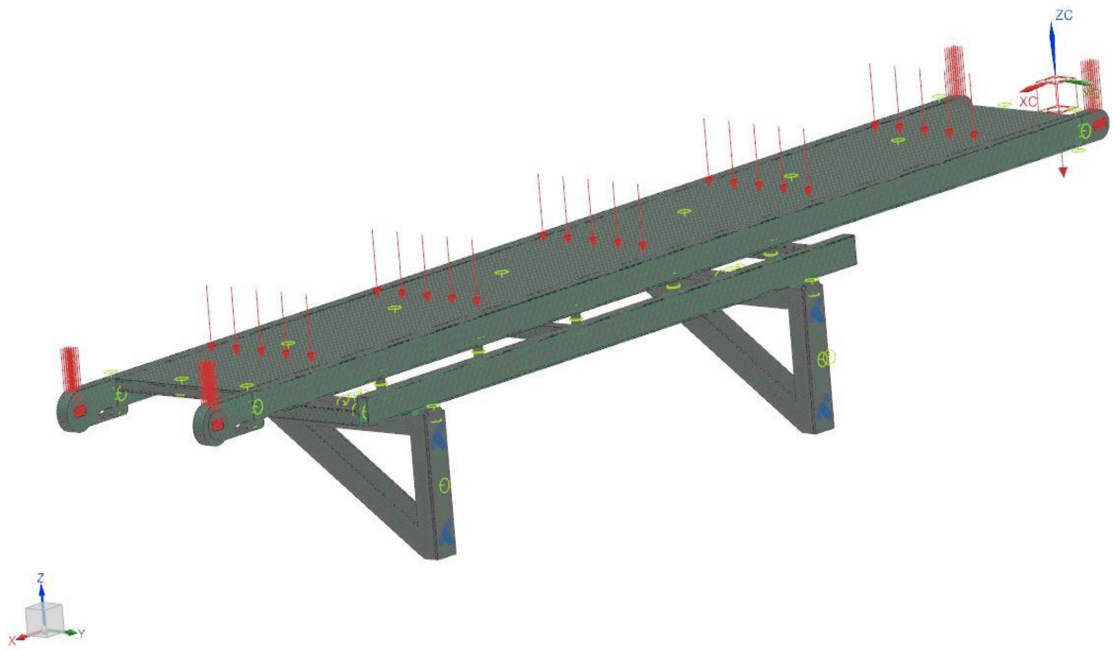


Figure 65 Loads and constraints applied on the conveyors model

Figure 65, there is a better view of the loaded model of the conveyor. The last step was selected solver, which will be used to run the process of the solution "SOL 101 Linear Statics – Global Constraints" and run the solution.

The results of the solution are shown in **Figures 67** and **68**. The first figure shows the results of the course of stress in the construction. The maximal stress found in the construction was 118.49 MPa, but this stress was (locally) placed in the part which is just simulation the attachment of the holders to the upper frame (**Figure 66**). There were replaced real profiles by idealised profile and for the real part, and the real solution prevents such high stress in this place.
Other most loaded places were holes where is the conveyor attached to the injection moulding machine (maximal 38,5 MPa).

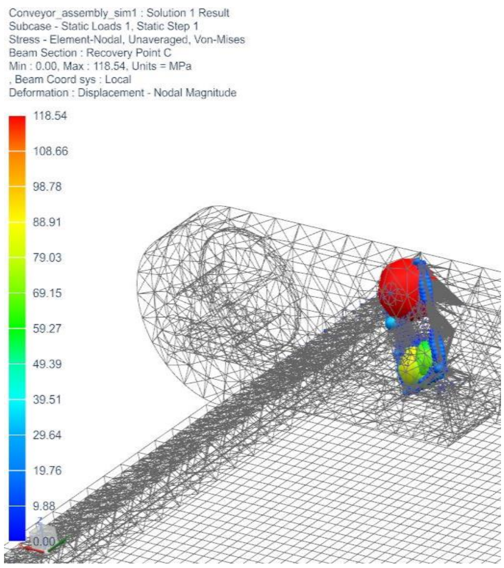


Figure 66 Maximal stress in holder attachment

Figure 67 RESULTS: Stress - Element - Nodal (Von Mises)

The next presented are the displacement results. The maximal displacement is 1.321 mm, and because of its placement on the longest unsupported part of the conveyor is this displacement acceptable.

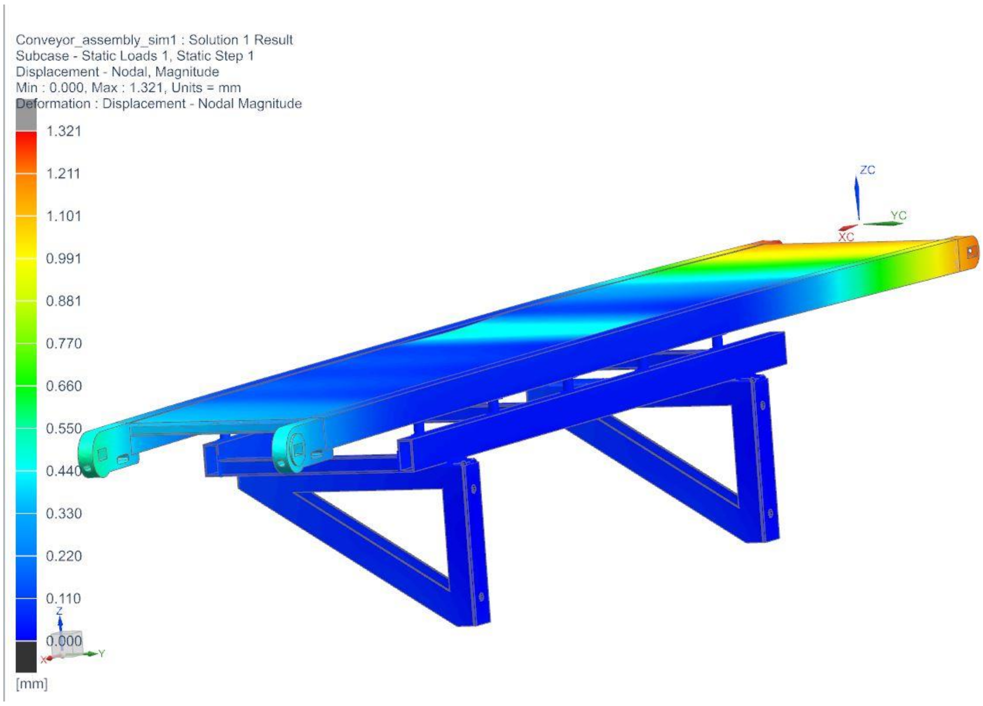
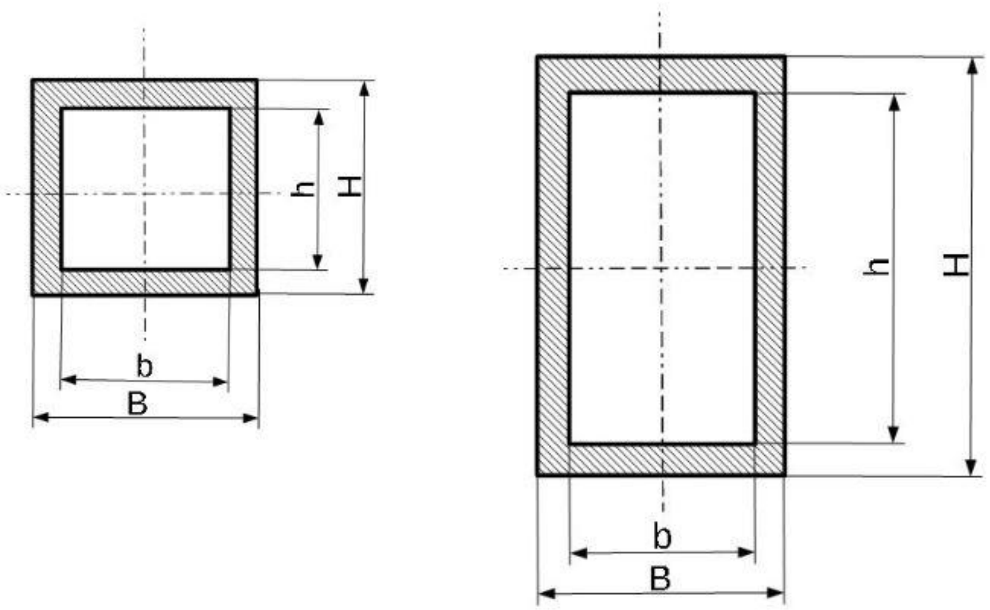


Figure 68 RESULTS: Displacement – Nodal

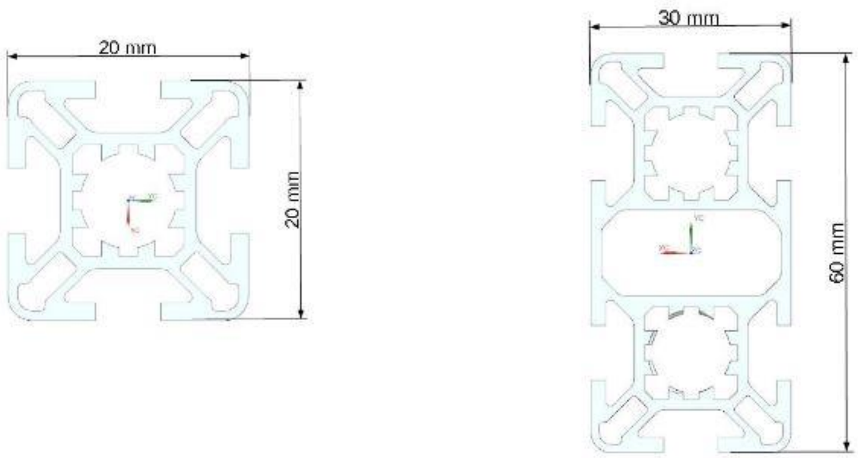
As was already mentioned above, there were some parts in the idealised model replaced by some others parts with similar shape but different cross-section. Next calculation will show the differences in stress results. In displacement will also be some differences but the not significant. Because of that will be solved just stress differences.

Equivalence of cross-sections of idealised part to the real part

Idealised cross-sections of replaced component



Real cross-sections of replaced components



Needed input values:

$B_1 := 20\ mm$	Width of idealised cross-section 20x20
$b_1 := 14 \cdot mm$	Internal width of idealised cross-section 20x20
$H_1 := 20\ mm$	Height of idealised cross-section 20x20
$h_1 := 14 \cdot mm$	Internal height of idealised cross-section 20x20
$B_2 := 30\ mm$	Width of idealised cross-section 60x30
$b_2 := 24 \cdot mm$	Internal width of idelised cross-section 60x30
$H_2 := 60\ mm$	Height of idealised cross-section 60x30
$h_2 := 54 \cdot mm$	Internal height of idealised cross-section 60x30
$W_{OB1} := 0.7 \cdot cm^3 = 700\ mm^3$	Cross-sectional modulus in bendig for original part 20x20
$W_{OB2} := 7.0 \cdot cm^3 = (7 \cdot 10^3)\ mm^3$	Cross-sectional modulus in bendig for original part 60x30

Calculation of cross-sectional modulus in bendig for original part 20x20:

$$W_{OR1} := \frac{B_1 \cdot H_1^{\ 3} - b_1 \cdot h_1^{\ 3}}{6 \cdot H_1} = (1.013 \cdot 10^3)\ mm^3$$

Calculation of cross-sectional modulus in bendig for original part 60x30:

$$W_{OR2} := \frac{B_2 \cdot H_2^{\ 3} - b_2 \cdot h_2^{\ 3}}{6 \cdot H_2} = (7.502 \cdot 10^3)\ mm^3$$

Ratio of both modules 20x20:

$$\frac{W_{OR1}}{W_{OB1}} = 1.447$$

Ratio of both modules 60x30:

$$\frac{W_{OR2}}{W_{OB2}} = 1.072$$

Recalculation of the maximum stress in profile 20x20:

$\sigma_{R1} := 4.45\ MPa$ Stress in the idealised component

$\sigma_{B1} := \sigma_{R1} \cdot 1.447 = 6.439\ MPa$ Stress in the original component.

Recalculation of the maximum stress in profile 60x30:

$\sigma_{R2} := 3.8\ MPa$ Stress in the idealised component

$\sigma_{B2} := \sigma_{R2} \cdot 1.447 = 5.499\ MPa$ Stress in the original component.

This calculation demonstrates the differences between idealised profiles and real user profiles. During this calculation was assumed that the bending mostly loads these recalculated profiles. All other loads were not assumed. The differences results are not too significant, so it can be said that the idealised part is, in this case, a suitable substitute for the real model in the simulation.

4.2.1.3. Powered roller holder FEM analysis

Next, quite loaded parts that were subjected to FEM analysis are powered roller holders (front holders. These two parts are predominantly similar so that they will be analysed just the right one form the front view.

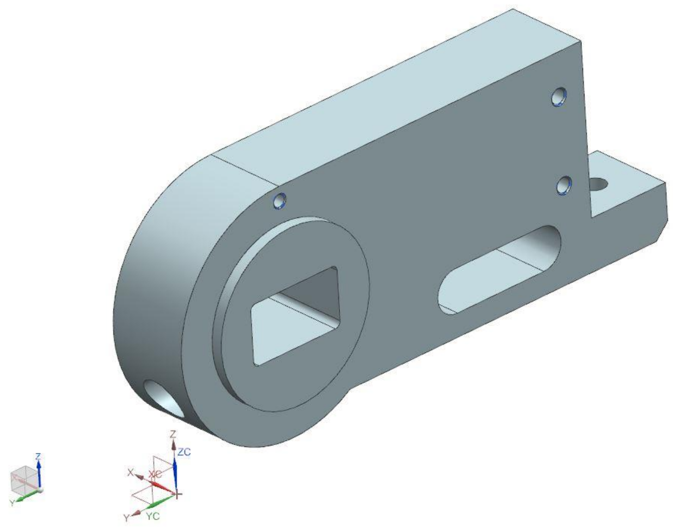


Figure 69 Idealised part (Front holder)

In **Figure 69** is shown the idealised body of the component. There was not necessary to make many changes; there were just deleted some chamfers and rounding.

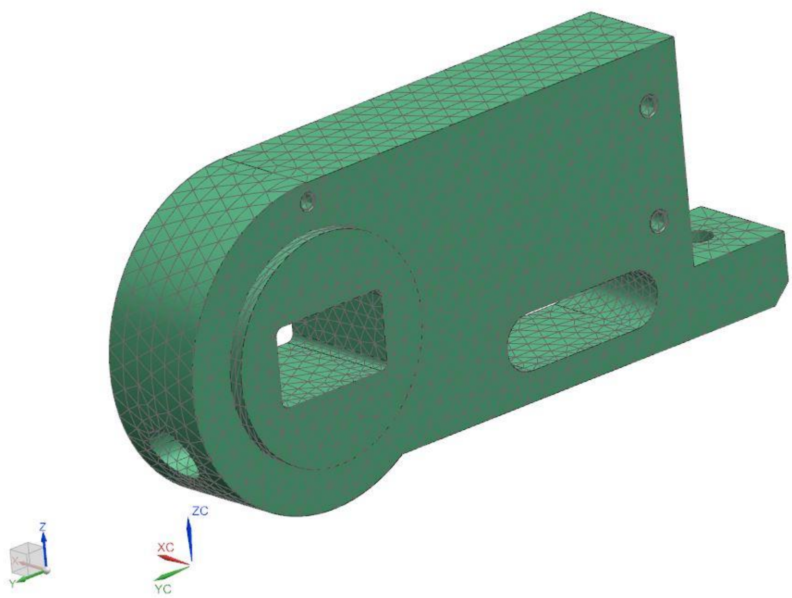


Figure 70 Meshed model (Front holder)

Front holder	
Selected options	
Type of the mesh:	3D Tetrahedral Mesh
Type of the element:	CTETRA(10)
Size of the element:	6
Material:	Aluminum_2014

Figure 71 Front holder (mesh properties)

In **Figure 70** is shown the meshed model of the front holder. Properties of this mesh are stated in **Figure 71**.

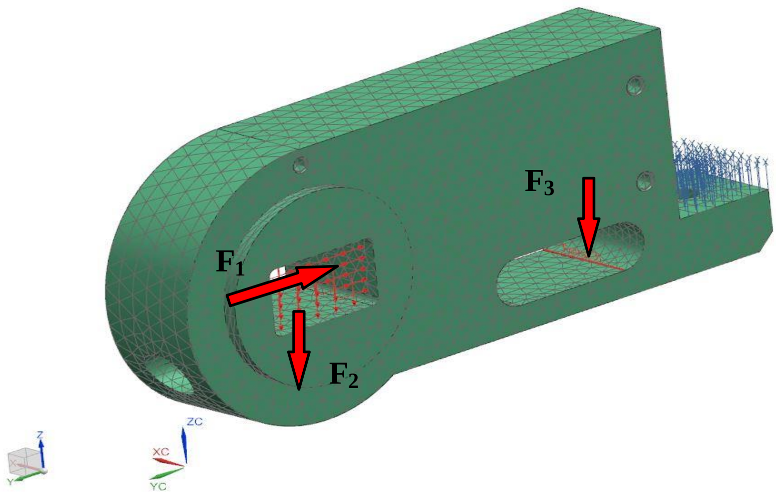


Figure 72 Loads and constraints applied on the model (Front holder)

Three main loads were necessary to use in this solution to simulate critical load on this component. The first one was load caused by tensioning force this load was simulated by force F1. The second one was load caused by the mass of powered roller and the maximal product standing o it was used force F2. The last one was load caused by the mass of adjusting roller; this one was replaced by force F3. Body of this component was attached using fixed constraint (holes for attaching sticks) and fixed translation in the Z direction (back supporting part).

Forces applied on the front roller holder	
Selected options	
F1	63 N
F2	300 N
F3	50 N

Figure 73 Loads applied to the model (Front holder)

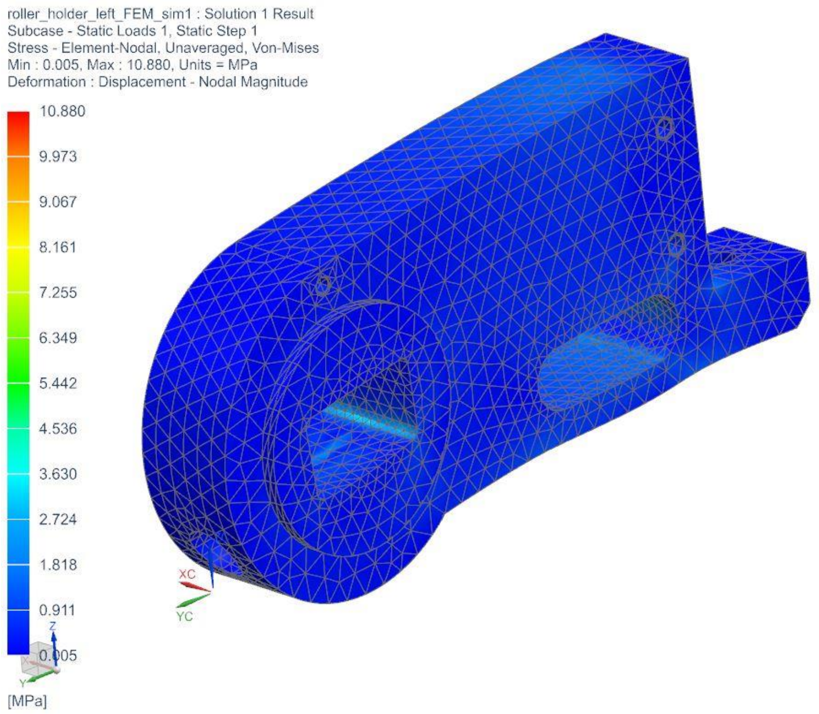


Figure 74 RESULTS: Stress - Element - Nodal (Von-Mises)

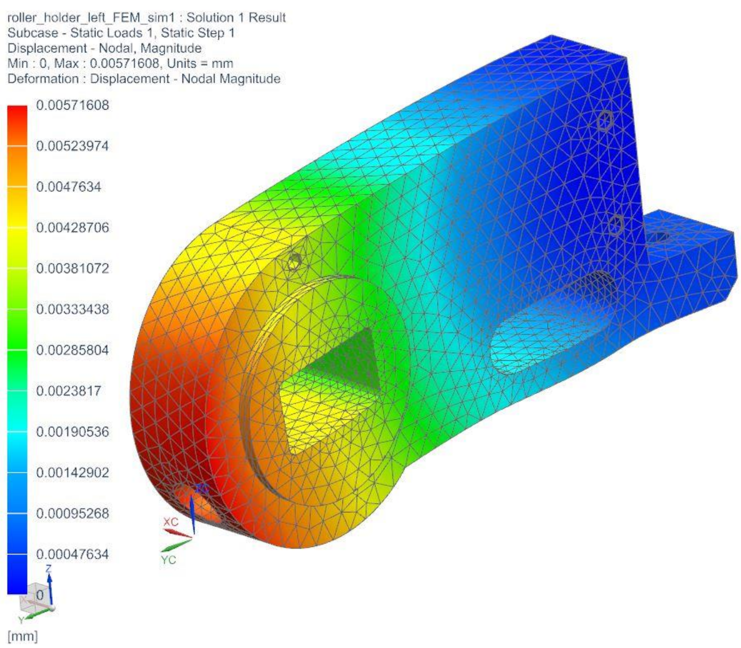


Figure 75 RESULTS: Displacement - Nodal

Figures 74 and **75** show the results of stress and displacement from the analysis solution. Maximal stress in the component is 10.88 MPa, and the critical place with this load was detected on edge inside the hole for attachment (in real part is this edge chamfered). Maximal displacement is 0,0057 mm, and that is a safe value.

4.2.1.4. Ejecting roller FEM analysis

Another loaded part is ejecting roller. As it was already mentioned, this component is used to enable pulling quickly out of the workspace of the injection moulding machine.

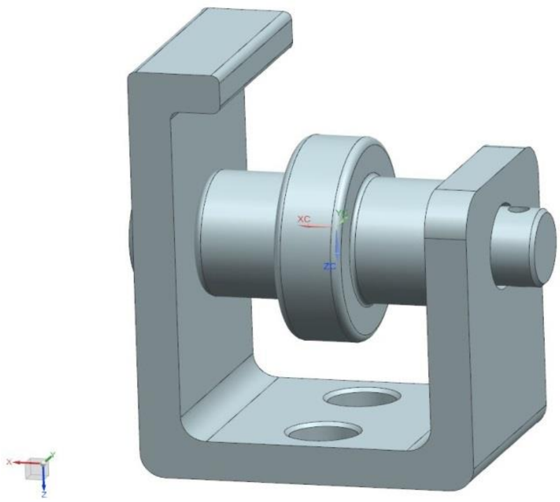


Figure 76 Idealised part (Ejecting roller)

Concerning the analysis, any smaller parts were deleted to reduce the complexity of the analysis; the shape was simplified.

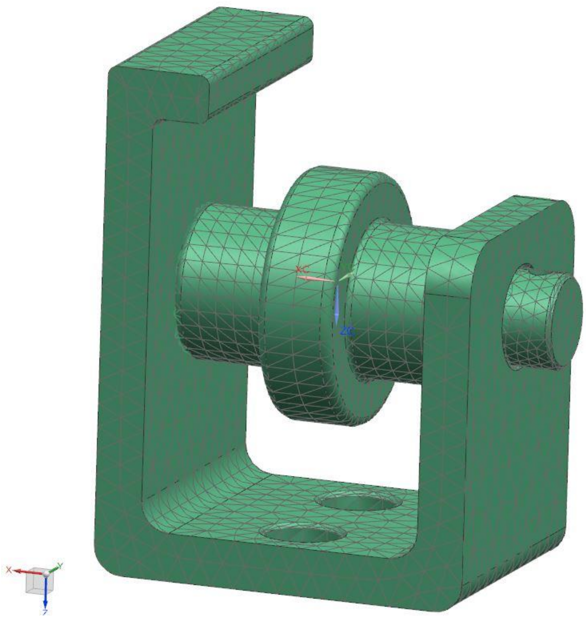


Figure 77 Meshed part (Ejecting roller)

On the previous picture is shown idealised model with the mesh. Properties of individual meshes are selected in **Figures 78, 79** and **80**.

Roller holder	
Selected options	
Type of the mesh:	3D Tetrahedral Mesh
Type of the element:	CTETRA(10)
Size of the element:	5
Material:	Steel

Figure 78 Roller holder (mesh properties)

Pin	
Selected options	
Type of the mesh:	3D Tetrahedral Mesh
Type of the element:	CTETRA(10)
Size of the element:	3
Material:	Steel

Figure 79 Pin (mesh properties)

Roller	
Selected options	
Type of the mesh:	3D Tetrahedral Mesh
Type of the element:	CTETRA(10)
Size of the element:	3,5
Material:	Steel

Figure 80 Roller (mesh properties)

In **Figure 81** is displayed how and where are the loads and constraints, placed.

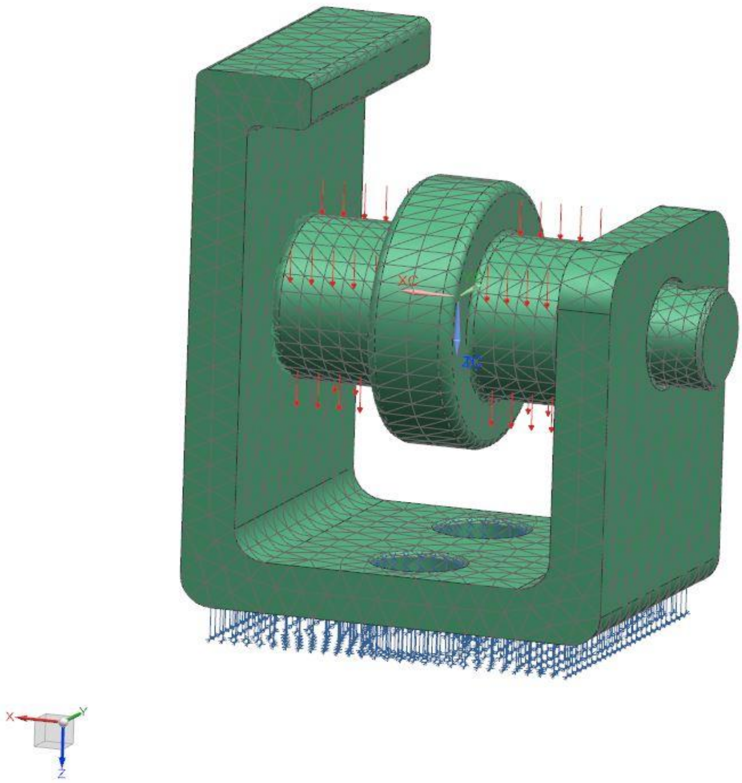


Figure 81 Loads and constraints applied on the model (Ejecting roller)

There is applied fixed constraint to the holes for attachment to the lower frame. The bottom side of the holder is fixed in translation in the Z direction.

The load applied is calculated from the previous analysis of entire conveyor construction.

$\sigma_{max} = 20MPa - maximal\ stress\ in\ the\ elements\ (replacing\ ejecting\ rollers)$

$d = 10mm - diameter\ of\ the\ element\ with\ circular\ cross - section$

$$\sigma_{max} = \frac{F}{S} => F = \sigma_{max} * S = 20 * \frac{\pi * d^2}{4} = 1570N$$

From this calculation will be used the force F = 1570 N like a force loading the roller. That means this analysis will try to simulate the worst case of load in components.

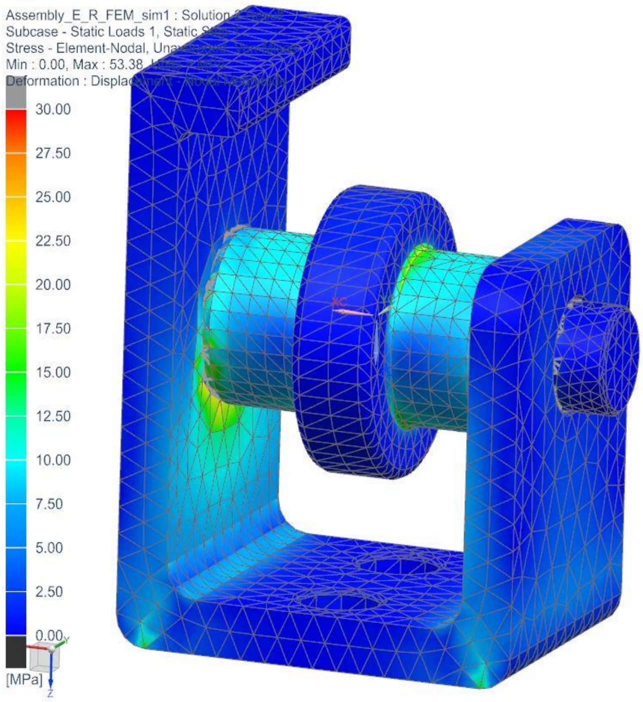


Figure 82 RESULTS: Stress - Element - Nodal (Von-Mises)

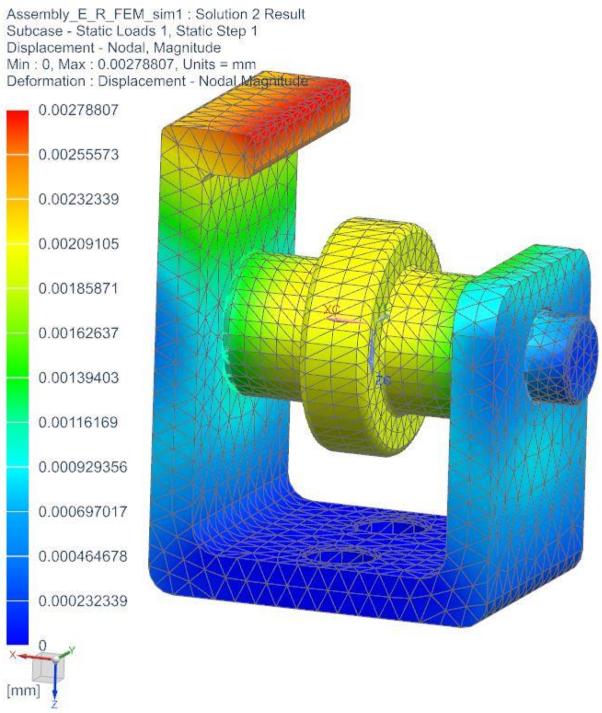


Figure 83 RESULTS: Displacement - Nodal

In **Figure 82** and **83** are displayed results from the analysis. Maximal stress in this module is 58,38 MPa, and as in the previous analysis, it is stress in the element placed on the sharp edge (will be in real reduced by the chamfer).
Maximal displacement from deformation in the whole model is 0,0028 mm. That can be considered as low value.

4.2.1.5. Calculations of bolts in supporting consoles (shear stress)

In this case, it will be considered that the two fitted bolts M20 in the single console are loaded by the mass of the conveyor and some reserve (unexpected load). When the conveyor has pulled out a large percentage of its mass will load one console. The approximate mass of the conveyor is 120 kg, and there will be added more 30 kg (product + some unexpected mass).

Needed input values:

$\sigma_{Dt} := 200\ MPa$ Tensile strenght for material EN 10025 (ČSN 11 500)

$l_1 := 200\ mm$

$d_B := 20\ mm$ Diameter of the bolt

$F_{GC} := 1500\ N$ Gravity force from conveyor

Bolt cross-section:

$$S_B := \frac{\pi \cdot d_B^{\ 2}}{4} = 314.159\ mm^2$$

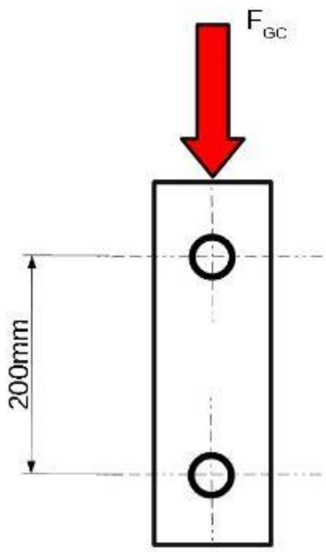
Shear stress in the bolt:

$$\tau_s := \frac{F_{GC}}{2 \cdot S_B} = 2.387\ MPa$$

Acceptable shear stress:
For steel will be used:

$$\tau_{Ds} := 0.6 \cdot \sigma_{Dt} = 120\ MPa$$

Shear stress in the bolt is acceptable, because $\tau_{Ds} > \tau_s$.



4.2.1.6. Calculation of bending stress of the sliding desk

In this calculation will be considered that the siding desk itself (without, for example, corners, holder) will be loaded by a mass of one product of maximal mass. The position of the desk will be horizontal (that means the position where is the load maximal).

Needed input values:

$\sigma_{Do} := 150\ MPa$ Tensile strenght for material EN 10025 (ČSN 11 500)

$W := 436 \cdot mm$ Width of the desk

$G_P := 150\ N$ Force inducted by one product of maximal dimensions

$l_1 := 370\ mm$

$T := 4\ mm$ Thickness of the desk

Bending moment (A):

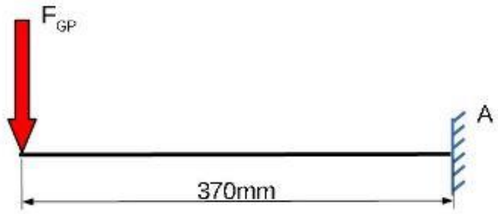
$M_O := G_P \cdot l_1 = (5.55 \cdot 10^4)\ N \cdot mm$

Desk cross-section modulus in bending:

$W_O := \frac{W \cdot T^2}{6} = (1.163 \cdot 10^3)\ mm^3$

Bending stress in desk:

$\sigma_O := \frac{M_O}{W_O} = 47.735\ (MPa)$



Bending stress is acceptable ($\sigma_{DO} > \sigma_O$).

4.2.1.7. Calculation of shear stress in sliding desk bolt

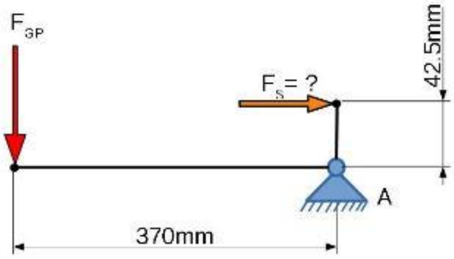
As in the calculation of the bending stress in the desk will be this desk loaded by the mass of one maximal product placed on the desk, and the desk will be adjusted horizontally. It is needed to realise that the desk is locked by two bolts (one on both sides).

Needed input values:

$\sigma_{Dt} := 200\ MPa$	Tensile strenght for material EN 10025 (ČSN 11 500)
$d := 5\ mm$	Diameter of the bolt
$F_{GP} := 150\ N$	Force inducted by one product of maximal dimensions
F_S	Shear force of the bolt
$l_1 := 370\ mm$	$l_2 := 42.5\ mm$

Moment caused by the mass of product:

$$M_A := F_{GP} \cdot l_1 = (5.55 \cdot 10^4)\ N \cdot mm$$



Shear force on bolt:

$$F_S := \frac{M_A}{l_2} = (1.306 \cdot 10^3)\ N$$

*Construction is simmetrically solved, due to that will be the half force Fs on one bolt.

Shear force on sigle bolt:

$$F_{SI} := \frac{F_S}{2} = 652.941\ N$$

Bolt cross-section:

$$S_B := \frac{\pi \cdot d^2}{4} = 19.635\ mm^2$$

Shear stress in the bolt:

$$\tau_s := \frac{F_{SI}}{S_B} = 33.254\ MPa$$

Acceptable shear stress:
For steel will be used:

$$\tau_{Ds} := 0.6 \cdot \sigma_{Dt} = 120\ MPa$$

Shear stress in the bolt is acceptable, because $\tau_{Ds} > \tau_s$.

4.2.1.8. Calculation of forces in the belt

This part of calculations focuses on the forces between the belt and supporting desk mostly caused by friction. It is needed to find the force which has to be used to tight the rollers to enable transporting of the product and prevent slipping of the belt on rollers. Most of the used values were already mentioned in the calculation of power input.

Calculation of forces in the belt:

$f := 0.6$	Friction coefficient for contact of PVC and steel [-]
$\alpha_G := 195°$	Belt angle
$\alpha_{Gr} := \alpha_G \cdot rad = 3.403\ rad$	Belt angle in radians
$T_2 := \frac{F_0}{e^{f \cdot \alpha_{Gr}} - 1} = 41.966\ N$	Force in the loaded belt (upper part)
$T_1 := F_0 + T_2 = 323.398\ N$	Force in the free belt (lower part)

Calculation of tensional force:

$Z_{min} := F_0 \cdot \frac{2}{e^{f \cdot \alpha_{Gr}} - 1} = 83.931\ N$	Operational tensional force to run the belt
$Z_R := 1.5 \cdot 2 \cdot T_2 = 125.897\ N$	Starting tensional force needed to run the belt

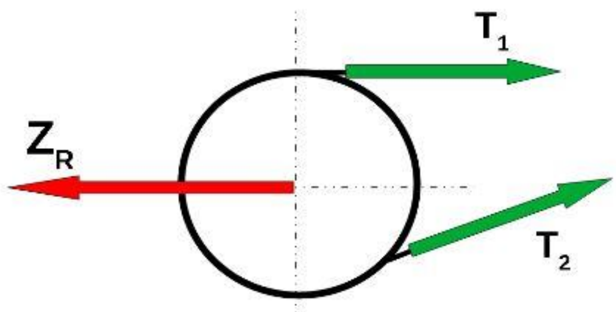


Figure 84 Forces calculation scheme

Due to the angle in the lower part of the belt force, T2 will be divided into two directions X and Y. For the calculation, this force was considered just in the Y direction.

4.2.1.9. Calculation of basic dynamic load rating for bearing in the back roller

Ball bearings 6204-2RSL [12] were selected as bearings in the back roller assembly. In this calculation will be checked the dynamical bearing capacity.

Bearing calculation 6204-2RSL:

$C_B := 13.5\ kN$ Basic dynamic capacity load rating of selected bearing [12]

a) Calculation of equivalent force:

Velocity: $v = 0.15\ \frac{m}{s}$

Force in the free belt $T_2 = 41.966\ N$

Rotation coefficient $V := 1$
Axial force $F_a := 0$
Radial force $F_r := 2 \cdot T_2 = 83.931\ N$
Coefficient $e := 0.30$
Coefficient $X := 1$
Coefficient $Y := 0$

$F_e := V \cdot X \cdot F_r + Y \cdot F_a$

$F_e := V \cdot X \cdot F_r = 83.931\ N$

b) Calculation of basic dynamic load rating:

Selected lifetime: $L_h := 10000\ hr$
Diameter (expected): $d_e := 57\ mm$
Speed:

$$n := \frac{(v \cdot 60)}{\pi \cdot d_e} = (3.016 \cdot 10^3)\ \frac{1}{min}$$

For ball berings: $m := 3$

$$C := \sqrt[m]{\frac{(L_h \cdot n)}{16667}} \cdot F_e = 4.004\ kN$$

Dynamic load is acceptable ($C_B > C$)

The basic dynamic load rating was calculated for lifetime 10000 hours, which is expected from the conveyor.

4.2.1.10. Calculation of basic dynamic load rating for bearing in the adjusting roller

As bearings in the adjusting roller assembly, ball bearings W 6302-2Z [13]were selected. In this calculation will be checked the dynamical bearing capacity.

Bearing calculation W 6302-2Z:

$C_B := 9.95\ kN$ Basic dynamic capacity load rating of selected bearing [13]

a) Calculation of equivalent force:

Velocity: $v = 0.15\ \frac{m}{s}$

Force in the free belt $T_2 = 41.966\ N$

Rotation coefficient $V := 1$
Axial force $F_a := 0$
Radial force $F_r := 2 \cdot T_2 = 83.931\ N$
Coefficient $e := 0.30$
Coefficient $X := 1$
Coefficient $Y := 0$

$$F_e := V \cdot X \cdot F_r + Y \cdot F_a$$

$$F_e := V \cdot X \cdot F_r = 83.931\ N$$

b) Calculation of basic dynamic load rating:

Selected lifetime: $L_h := 10000\ hr$
Diameter (expected): $d_e := 50\ mm$
Speed:

$$n := \frac{(v \cdot 60)}{\pi \cdot d_e} = \left(3.438 \cdot 10^3\right)\ \frac{1}{min}$$

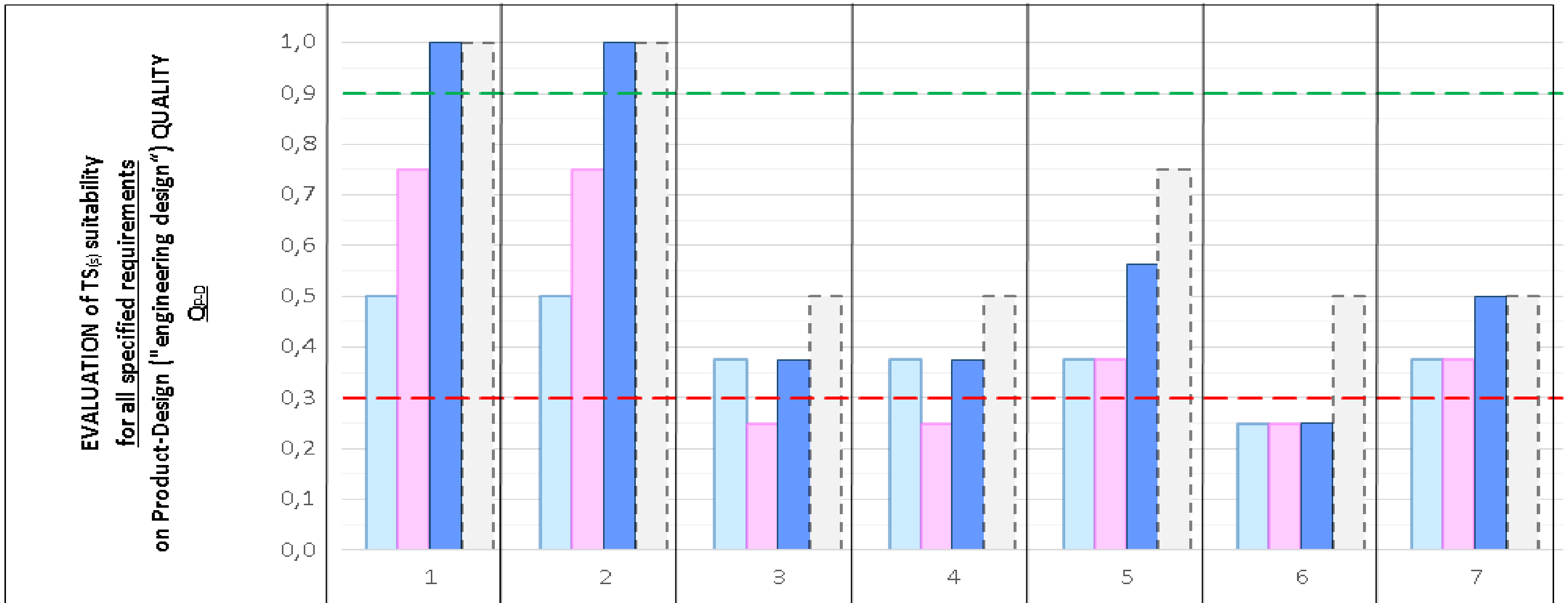
For ball berings: $m := 3$

$$C := \sqrt[m]{\frac{(L_h \cdot n)}{16667}} \cdot F_e = 4.183\ kN$$

Dynamic load is acceptable ($C_B > C$)

As in the calculations of basic dynamic load rating for back roller bearings was also in this case calculated for lifetime 10000 hours, which is expected from the conveyor.

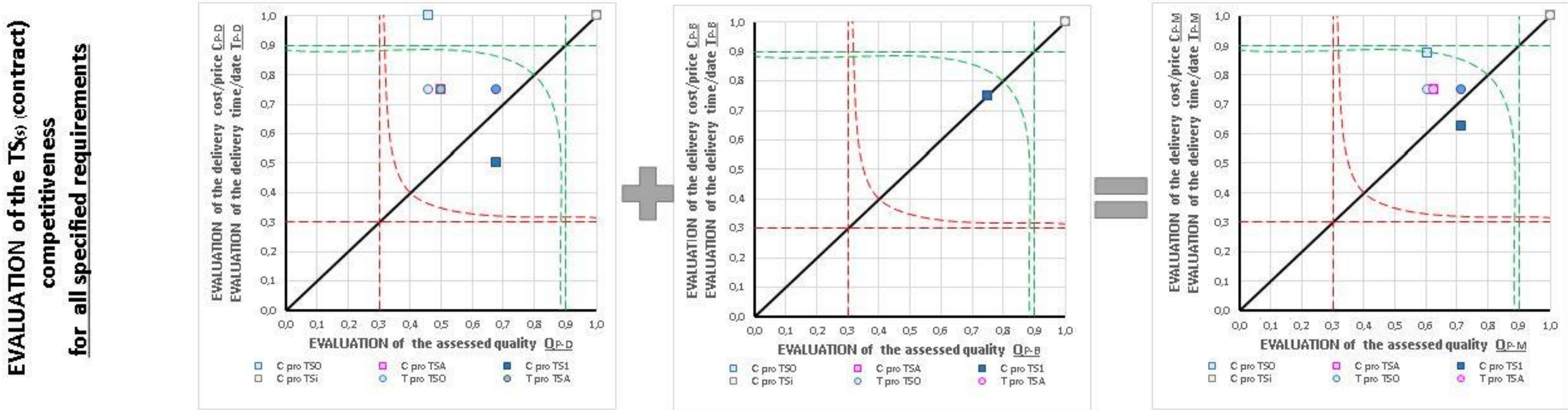
4.2.2. Summary SWOT evaluation of the starting, competitive and designed TS for requirements specification.



Return to Requirements Specif. & SWOT Evaluation:		◄◄ REQ.SPEC&SWOT	◄◄ REQ.SPEC&SWOT	◄◄ REQ.SPEC&SWOT	◄◄ REQ.SPEC&SWOT	◄◄ REQ.SPEC&SWOT	◄◄ REQ.SPEC&SWOT	◄◄ REQ.SPEC&SWOT
QP-D class of properties / requirements on TS (contract) :		1. TS(s) properties to its functionality (incl. operability) TS(s)	2. TS(s) properties to humans (& animals, ...) HuS	3. TS(s) properties to other tangible working means TS	4. TS(s) properties to active&reactive environment AREnv	5. TS(s) properties to „know-how" information IS	6. TS(s) properties to „know-SMQ" information MgtS	7. TS(s) properties to its constr.structure (incl.feature&react.pr.) TS(s)
TS Life Cycle stage :		operation	all !	all !	all !	all !	all !	indirectly all !
Weight of properties / requirements (0 - 4) :		4	4	2	2	3	2	2
Results of the weighted SWOT evaluation (0 - 1)	**Starting TS0**	0,50	0,50	0,38	0,38	0,38	0,25	0,38
	Competitive TSA	0,75	0,75	0,25	0,25	0,38	0,25	0,38
	Designed TS1	**1,00**	**1,00**	**0,38**	**0,38**	**0,56**	**0,25**	**0,50**
	Ideal TSi	1,00	1,00	0,50	0,50	0,75	0,50	0,50

Figure 85 Results of SWOT evaluation of suitability of starting TS0, competit. TSA, designed TS1 and refer. ideal TSi [26]

4.2.3. Summary SWOT evaluation of the mutual competitiveness of the starting, competitive and designed TS



Return to Requirements Specif. & SWOT Evaluation:		◄◄ REQ.SPEC&SWOT	◄◄ REQ.SPEC&SWOT	◄◄ REQ.SPEC&SWOT	◄◄ REQ.SPEC&SWOT	◄◄ REQ.SPEC&SWOT	◄◄ REQ.SPEC&SWOT	◄◄ REQ.SPEC&SWOT	◄◄ REQ.SPEC&SWOT	◄◄ REQ.SPEC&SWOT
Q^T^C area of properties / requirements on the TS (concract):		Q_{P-D} PRODUCT-DESIGN („engineering design") TS(s) CONTRACT QUALITY	T_{P-D} PRODUCT-DESIGN („engineering design") TS(s) CONTRACT TIME / DATE	C_{P-D} PRODUCT-DESIGN („engineering design") TS(s) CONTRACT COSTS / PRICE	Q_{P-B} PRODUCT-BUSINESS („business") TS(s) CONTRACT QUALITY	T_{P-B} PRODUCT-BUSINESS („business") TS(s) CONTRACT TIME / DATE	C_{P-B} PRODUCT-BUSINESS („business") TS(s) CONTRACT COSTS / PRICE	Q_{P-M} PRODUCT-MARKET („market") TS(s) CONTRACT QUALITY	T_{P-M} PRODUCT-MARKET („market") TS(s) CONTRACT TIME / DATE	C_{P-M} PRODUCT-MARKET („market") TS(s) CONTRACT COSTS / PRICE
TS Life Cycle stage :		distribution	distribution	distribution	distribution	distribution	distribution	distribution	distribution	distribution
Weight of properties / requirements (0 - 4) :		4	4	4	4	4	4	4	4	4
Results of the weighted SWOT evaluation (0 - 1)	Starting TS0	0,46	0,75	1,00	0,75	0,75	0,75	0,60	0,75	0,88
	Competitive TSA	0,50	0,75	0,75	0,75	0,75	0,75	0,63	0,75	0,75
	Designed TS1	**0,68**	**0,75**	**0,50**	**0,75**	**0,75**	**0,75**	**0,71**	**0,75**	**0,63**
	Ideal TSi	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00

Figure 86 Results of SWOT evaluation Q^T^C P-D / P-B / P-M competitiveness for all comparable requirements for the designed TS [26]

Results of the SWOT evaluation

The chart showed in **Figure 85** shows the results of the evaluation of suitability of starting (TS0), competitive (TSA), designed (TS1), and the ideal (TSi) product. This evaluation includes an evaluation of every single requirement from the requirements specification, and the results are divided into individual sections. From the mentioned chart, it is very transparently showed that the designed product is very strong in "properties to its functionality" and "properties to human". In these two groups is the score of designed product same as of the ideal product, due to that can be said that in these two groups fulfils the product selected requirements at most as it can. Rest of the sections also shows good results except the penultimate section "properties to know-SMQ information" where is the evaluation same for all three product (designed, starting and competitive). The third section "properties for the tangible working means" reports the same results for the designed product as for the starting product. The same situation as in the third section is in the fourth section because in this section are results for designed and starting products also the same. In the fifth section overcomes the designed product the starting product and the competitive product, but it is still not enough to equalise the ideal product.

In **Figure 86**, there is also an added chart showing the competitiveness comparison of starting (TS0), competitive (TSA), designed (TS1), and the ideal (TSi) product. The ideal product is located in the top left corner, and it is connected with the starting point (0) of the chart by narrow line. This line highlights the ideal balance of delivery costs/time and accessed quality. The designed product in this case also reports quite a successful result because its accessed quality from all of the product (except the ideal product) is highest and but there is, unfortunately, the fact that its piece is higher than in other product. However, it is difficult to compare product which offers some functions (in this case functions for the disabled operator) with other product do not offer it.

5. FINAL ELABORATION

This chapter will introduce the output (product) of this engineering design process and describe the main advantages and disadvantages. There will also be created some conclusion of the work.

5.1. Final product

The final product (shown in **Figure 87**) offers easy usage and working environments for the disabled operator. Its highest advantage is the possibility of adjusting the height of the sliding desk in width range. For the best results of the conveyor usage, it is recommended to equip the workplace with an adjustable table that allows for the potential operator (using a wheelchair) to take the products transported by the conveyor from the table. This desk can also be used in the case when the product falls directly from the conveyor into some storage box (small products) because the sliding desk reduces the risk of damage to the product by the fall shocks. This alternative can also be used in normal operations because if the desk is not needed, it can be easily turned down. The next significant advantage of this product is the simple and easy opportunity to pull the conveyor out of the injection moulding machine workspace because of the ejecting rollers track. This track reduces the friction between both parts of the frame and replaces it by the rolling resistance. When the centre of gravity is out of the upper part goes on the ejected part, the frame will be still locked against carrying because of specially shaped roller holders.

Figure 87 Final design of the conveyor

6. SUMMARY AND CONCLUSION

The primary goal of this document was to design a product focused on the disabled operator and "SMART" function for company ENGEL. This dissertation was a part of the Multidisciplinary Project in an International Context. Due to that was the whole dissertation written in the English language.

For the elaboration of this dissertation was used software NX 12 from company SIEMENS and MATHCAD prime 5.0.0.0 from company PTC.

The engineering design process was led mostly like the designing of a new product. Some of parts and solutions were inspired by the starting product solution from company ENGEL. During this process was the product evaluated and compared with the starting, competitive and ideal product to obtain the most suitable solution. The construction of the conveyor was supported by experiences from company ENGEL, calculations of the critical sections and FEM analysis. The result of this engineering design process is the new solution of the conveyor focusing on the ergonomics and safety of the disabled service (operator).

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Appendix no. 1

Companies which were used as competitors

Links on competitive companies

KRAUS: https://kraus-austria.com/en/conveyor-rollers
INTERROLL: https://www.interroll.cz/
DORNER: https://www.dornerconveyors.com/europe
CRIZAF: https://www.crizaf.com/
MK –Technology Group: https://www.mk-group.com/start.html
MTF: https://www.mtf-technik.de/en
TEVCO:
https://tevco.cz/dopravniky?gclid=Cj0KCQjwoKzsBRC5ARIsAITcwXEskqk8AIbQRT5TasZktXrtogO_KRtzA9D6gbEYPNUBuHUjC982ZmIaAjOcEALw_wcB
LOGSYS: https://www.logsys.cz/cs/druhy-dopravniku
HABERKORN: https://www.haberkorn.cz/dopravniky/
ALUTEC KK: https://www.aluteckk.cz/pasove-dopravniky
BLUETECH: https://www.bluetech.cz/pasove-dopravniky
ALVÁRIS: https://www.alvaris.eu/cz/dopravniky/dopravniky
TMT: http://www.tmt.cz/cz/
ADAPT: http://www.adaptdopravniky.cz/
INDUCTLINE: http://www.inductline.cz/Dopravniky
OSTROJ: http://www.ostroj.cz/hreblove-dopravniky
MARTING: http://www.marting.cz/

Appendix no. 2

Requirements specification [26]

(α) SPECIFICATIONS & EVALUATION:	TS(s) properties / contract REQUIREMENTS SPECIFICATION	SWOT EVALUATION OF THE TS(s) SUITABILITY FOR THE SPECIFIED REQUIREMENTS		
	Requirements specification and TS suitability evaluation is linked only in a simplified way by equivalent quality classes	*Optional recommended limits:*	*lower limit:* 0,3 *of max 1.*	*upper limit:* 0,9 *of max. 1.0*
TS(s) :	Integrated Conveyor Belt	Starting TS0	Competitive TSA	Designed TS1
		ENGEL HLi 2900Lx350W	ALL	ENGEL NEW
ENG.DESIGN PHASE: EDSM sub-phase: Step/Order of solut. in	*I. ELABORATING THE PROBLEM* Establishing requirements specification for TS (Part of the phase: 1. Establishing requirements specification for TS and project solution plan) i. Requirements specification for TS / 1	*I. I. ELABORATING THE PROBLEM* 1.a Establish. requirem. specification for TS ii.b SWOT-starting TS for requir. spec./ 2	*I. I. ELABORATING THE PROBLEM* 1.a Establish.requirem.specif. for TS ii.b SWOT -competit.TS for requir.spec./ 3	*III. CONSTRUCTIONAL DESIGN* ii.b SWOT - designed TS for requir. spec./ 7
Rating limitations ?:	*Is it possible to predict values of all specified property/requirement indicators for the evaluated TS? :*	YES => Eval. possible	YES => Eval. possible	YES => Eval. possible

						TS0 ∑ V.HODNOCENÍ n x (0÷4)	TS0 V.HODNOC. (0÷4)	TS0 V.HODNOC. (0÷1)	TSA ∑ V.HODNOCENÍ n x (0÷4)	TSA V.HODNOC. (0÷4)	TSA V.HODNOC. (0÷1)	TS1 ∑ V.HODNOCENÍ n x (0÷4)	TS1 V.HODNOC. (0÷4)	TS1 V.HODNOC. (0÷1)
QTC_{P-M} PRODUCT-MARKET ("market") TS(s) CONTRACT QUALITY *- on handover of the TS(s) to the receiving customer (usually to direct user at the end of distribution)*						23,78	2,97	0,74	22,67	2,83	0,71	22,28	2,78	0,70
QTC_{P-D} PRODUCT-DESIGN („engineering design") TS(s) CONTRACT QUALITY *- on handover of the TS(s) to the receiving customer (usually to direct user at the end of distribution)*				WEIGHT in QTCP-M (0÷4) 4		35,33	2,94	0,74	32,00	2,67	0,67	30,83	2,57	0,64
QTC_{P-D} PRODUCT-BUSINESS („commercial") TS(s) CONTRACT QUALITY *- on handover of the TS(s) to the receiving customer (usually to direct user at the end of distribution)*				WEIGHT in QTCP-M (0÷4) 4		36,00	3,00	0,75	36,00	3,00	0,75	36,00	3,00	0,75
Q_{P-M} PRODUCT-MARKET („market") TS(s) CONTRACT QUALITY *- on handover of the TS(s) to the receiving customer (usually to direct user at the end of distribution)*			SUITABILITY diagrams ▶ DIAGRAMS Q^T^C ▶	WEIGHT in QTCP-M (0÷4) 4		19,33	2,42	0,60	20,00	2,50	0,63	22,83	2,85	0,71
Q_{P-D} PRODUCT-DESIGN („engineering design") TS(s) CONTRACT QUALITY *- on handover of the TS(s) to the receiving customer (usually to direct user at the end of distribution)*			SUITABILITY diagrams ▶ DIAGRAMS Q^T^C ▶	WEIGHT in QP-M (0÷4) 4		44,00	1,83	0,46	48,00	2,00	0,50	65,00	2,71	0,68
I. DOMAIN of the REFLECTED TS(s) PROPERTIES - in relations to the TS life cycle (LC)														
I.a Reflected TS(s) properties to Operating Transformation Process incl. its Operand - to the Operating stage of the TS life cycle (LC)														
Properties requirements to TS(s) / TS(s) contract *i Class / i.j Subclass / • Section/Subsection / - indicator*	Value *(quantitative/qualitative)* *of requirement/property*	Category of the requir. source	Eliminating of evaluat. (& diagrams)	Requir.equival. quality class of indicators	WEIGHT in Q_{P-D}	Achieved equiv. quality class of indicators	Evaluation of equivial. suitability	WEIGHTed evaluation of eq.suit.	Achieved equiv. quality class of indicators	Evaluation of equivial. suitability	WEIGHTed evaluation of eq.suit.	Achieved equiv. quality class of indicators	Evaluation of equivial. suitability	WEIGHTed evaluation of eq.suit.

23	1 **TS(s) properties to its functionality** (in the operation LC stage)			DIAGRAMS ▶▶	(° ÷ ****)	(0 ÷ 4)	(° ÷ ****)	(0 ÷ 4)	(0 ÷ 1)	(° ÷ ****)	(0 ÷ 4)	(0 ÷ 1)	(° ÷ ****)	(0 ÷ 4)	(0 ÷ 1)
0	***1.1 Suitability for the required output functions and effects***		**Select from**	Comparable											
0	*(most specific to operator, more general to operand & assisting inputs, most general to process):*		**the menu**	for all TS?											
0	***to TS OPERATOR:***	**Integrated Conveyor Belt**	---	---											
0	**● Create a transport way for injection mold products**		---	---											
1	*Maximal load cpacity*	*15kg*	*STATED/ASS.*	NO											
1	*Space on the conveyor*	*2900 mm x 350 mm*	*OBLIGATORY*	NO											
	Temperature resistence	min 100°C	*STATED/ASS.*												
1	*Belt guide*	centration of belt	*GEN.IMPLIED*	NO											
0	**● Allow safety environment for operator**		---	---											
1	*Height of the conveyor*	min. 1000 mm	*OBLIGATORY*	NO											
	Protection of service	covering	*GEN.IMPLIED*												
1	Noise	low	*OWN*	NO											
0	**● To work with injection molding machine**		---	---											
1	*Allow the service of injection mold*	extendability	*STATED/ASS.*	NO											
1	*Cooperation*	tacting	*OBLIGATORY*	NO											
0	**● Multipurpose**		---	---											
1	*Feed setting*	adjustable	*GEN.IMPLIED*	YES											
1	*Speed setting*	adjustable	*OWN*	YES											
0	***to OPERAND&Ass.Inp.:***	**Product and assisting M, E, I**	---	---											
0	**• Properties**		---	---											
1	*Maximal weight*	5 kg	*OWN*	NO											
1	*Maximal dimensions*	280x280x280	*OWN*	YES											
1	*Temperature*	25°C - 100°C	*GEN.IMPLIED*	YES	********	**4**	******	**2**	0,50	*******	**3**	0,75	********	**4**	1,00
1	*Shape*	complex	*GEN.IMPLIED*	YES											
0	***to PROCESS:***	**Sensoring, checking, etc**	---	---											
0	**● Product transporting**		---	---											
1	*Frugality*	high	*OBLIGATORY*	NO											
1	*Accuracy*	high	*OBLIGATORY*	YES											
0				0											
0	***1.2 Suitability for the required operability (in terms of location, time, service, ...):***		**Select from**	Comparable											
0	*• Base / supporting TS, • M,E,I connected to base/suport. TS, • Space requirements, • Working*		**the menu**	for all TS?											
0	*• Durability, • Frequency of use, • Reliability, etc.*														
0	*• Operator training, • Maintenance, • Repair, etc.*														
0	**• Location and environment**		---	---											
1	*Work environment*	dusty	*OBLIGATORY*	YES											
1	*Foundations*	flat floor	*OBLIGATORY*	YES											
1	*Portability*	easy	*OBLIGATORY*	YES											
0	**• Time range**		---	---											
1	*Frequence of use*	*daily*	*OBLIGATORY*	YES											
1	*Lifetime*	*5 years*	*STATED/ASS.*	YES											
0	**• Assistance processes (service,...)**		---	---											
1	*Maintenace*	*very low*	*OBLIGATORY*	YES											
1	*Service*	*very low*	*OBLIGATORY*	YES											
1	*Composition*	*very low*	*OBLIGATORY*	YES											
0				0											

I.b Reflected TS properties to Complex Operators of LC Transf. Systems (TrfS) - in INDIVIDUAL STAGES (!) of the TS life cycle (LC)														
Properties requirements to TS(s) / TS(s) contract *i Class / i.j Subclass / • Section/Subsection / - indicator*	**Value** *(quantitative/qualitative) of requirement/property*	**Category of the requir. source**	Eliminating of evaluat. (& diagrams)	Requir.equival. quality class of indicators	WEIGHT in Q_{P-D}	Achieved equiv. quality class of indicators	Evaluation of equvial. suitability	WEIGHTed evaluation of eq.suit.	Achieved equiv. quality class of indicators	Evaluation of equvial. suitability	WEIGHTed evaluation of eq.suit.	Achieved equiv. quality class of indicators	Evaluation of equvial. suitability	WEIGHTed evaluation of eq.suit.
2 TS(s) properties to humans (& animals, ...) in the LC stages			DIAGRAMS ►►	(° ÷ ****)	(0 ÷ 4)	(° ÷ ****)	(0 ÷ 4)	(0 ÷ 1)	(° ÷ ****)	(0 ÷ 4)	(0 ÷ 1)	(° ÷ ****)	(0 ÷ 4)	(0 ÷ 1)
***2.1 Suitability for values of humans** (animals, ...)* • *Life, social, etc. values (in opinions, customs,...)*		**Select from the menu**	Comparable for all TS?	***	4	**	2	0,50	*	3	0,75	***	4	1,00
• Operation		---	---											
Cultural use of conveyor	*high*	*GEN.IMPLIED*	NO											
			NO											
***2.2 Suitability for safety and health of humans** (&animals, ...)* • *Safety (for all living beings!), • Hygiene, • Ergonomics, etc..*		**Select from the menu**	Comparable for all TS?											
• Pre-manufacturing stages, manufacturing		---	---											
Safety of used materials	*very high*	*GEN.IMPLIED*	YES											
• Operation:		---	---											
Adjustability	*high*	*OBLIGATORY*	NO											
Dangerous parts	*minimal*	*OBLIGATORY*	NO											
Materials	*safe*	*OBLIGATORY*	NO											
Accident prevention	*high*	*OBLIGATORY*	NO											
Control	*simple*	*OBLIGATORY*	NO											
			0											
***2.3 Suitability for friendliness to human** (&animals, ...)* •*Appearance, •Noise, •Smell, •Touch, •Taste, (for sight, hearing, touch, smell, taste, feelings,...), etc.*		**Select from the menu**	Comparable for all TS?											
• Service, other stages adequately		---	---											
Noice	*low*	*GEN.IMPLIED*	YES											
Touch confort	*high*	*GEN.IMPLIED*	NO											
Color design	*high*	*OBLIGATORY*	NO											
			0											
3 TS(s) properties to other tangible working means in the LC stages			DIAGRAMS ►►	(° ÷ ****)	(0 ÷ 4)	(° ÷ ****)	(0 ÷ 4)	(0 ÷ 1)	(° ÷ ****)	(0 ÷ 4)	(0 ÷ 1)	(° ÷ ****)	(0 ÷ 4)	(0 ÷ 1)
3.1 Suitability for available tangible working means • *Compatibility with available and collaborative. tangible working means (ie. "technology"), etc.*		**Select from the menu**	Comparable for all TS?	***	2	**	3	0,38	**	2	0,25	**	3	0,38
• Pre-production LC stages:		---	---											
Demands on existing TS & Tg	*standard*	*OBLIGATORY*	YES											
• Production:		---	---											
Demands on production and assembly	*locksmith works*	*OBLIGATORY*	YES											
Demands on quality control of production and testing	*standard*	*OBLIGATORY*	YES											
Kind of production	*seriál*	*OBLIGATORY*	YES											
• Distribution:		---	---											
Storage space	*minimal*	*OBLIGATORY*	YES											
Handling during transport and installation	*simple TS*	*OBLIGATORY*	YES											
Means of transport	*vehicles, airplanes, ships*	*OBLIGATORY*	YES											
• Disposal:		---	---											
Demountability	*simple*	*OBLIGATORY*	YES											
Separability of materials	*simple*	*OBLIGATORY*	YES											
Recyclability of materials	*high*	*OBLIGATORY*	YES											
			0											
3.2 Suitability for new needed tangible working means • *Optimal ambitiousness on new tangible working means (availability, inexpensive,...), etc.*		**Select from the menu**	Comparable for all TS?											
• All LC stages:		---	---											
Demands on new needed TS & Tg (incl. co-op)	*none*	*OBLIGATORY*	YES											
			0											

Properties requirements to TS(s) / TS(s) contract *i Class / i.j Subclass / • Section/Subsection / - indicator*	Value *(quantitative/qualitative) of requirement/property*	Category of the requir. source	Eliminating of evaluat. (& diagrams)	Requir.equival. quality class of indicators	WEIGHT in QP-D	Achieved equiv. quality class of indicators	Evaluation of equival. suitability	WEIGHTed evaluation of eq.suit.	Achieved equiv. quality class of indicators	Evaluation of equival. suitability	WEIGHTed evaluation of eq.suit.	Achieved equiv. quality class of indicators	Evaluation of equival. suitability	WEIGHTed evaluation of eq.suit.
4 TS(s) properties to working&nature&space **environments** of the LC st.			DIAGRAMS ▶▶	(° ÷ ****)	(0 ÷ 4)	(° ÷ ****)	(0 ÷ 4)	(0 ÷ 1)	(° ÷ ****)	(0 ÷ 4)	(0 ÷ 1)	(° ÷ ****)	(0 ÷ 4)	(0 ÷ 1)
4.1 Suitability for acting working&natural&space environments *• Resistance to material & energy effects of environments, etc.*		Select from the menu	Comparable for all TS?											
• All LC stages:		---	---											
Weather resistance	*proportional to indoor use*	*OBLIGATORY*	YES											
Corrosion resistance	*high*	*OBLIGATORY*	YES											
			0											
4.2 Suitability for impacts on working & natural & space environments *• Ecology of material & energy inputs, • Ecology of material & energy outputs*		Select from the menu	Comparable for all TS?	***	2	**	3	0,38	**	2	0,25	***	3	0,38
• All LC stages:		---	---											
Ecology of used materials and processess	*high*	*OBLIGATORY*	NO											
Ecology of used assisting materials and processes	*high*	*OBLIGATORY*	YES											
The need for materials and energy	*minimal*	*OBLIGATORY*	YES											
Ecology of output materials and energy	*high*	*OBLIGATORY*	YES											
Amount of secondary output materials and energy	*minimal*	*OBLIGATORY*	YES											
			0											
5 TS(s) properties to „know-how" information in the LC stages		&	DIAGRAMS ▶▶	(° ÷ ****)	(0 ÷ 4)	(° ÷ ****)	(0 ÷ 4)	(0 ÷ 1)	(° ÷ ****)	(0 ÷ 4)	(0 ÷ 1)	(° ÷ ****)	(0 ÷ 4)	(0 ÷ 1)
5.1 Suitability for available "know-how" information *• Compatibility with available "know-how" information, knowledge, experience ("inf.technology"), etc.*		Select from the menu	Comparable for all TS?											
• All LC stages:		---	---											
Regulations and standards (including safety)	*no violation*	*OBLIGATORY*	YES											
			0											
5.2 Suitability for needed "know-how" information *• Optimal demands on new "know-how" inf., knowledge, experience (availability, low cost, ...), etc.*		Select from the menu	Comparable for all TS?	***	3	*	2	0,38	*	2	0,38	***	3	0,56
• Production:		---	---											
Production and assembly documentation	*standard*	*OBLIGATORY*	YES											
• Service:		---	---											
Operating, maintenance and repair manuals	*needed*	*OBLIGATORY*	YES											
Introductory training	*needed*	*OBLIGATORY*	YES											
• Other LC stages:		---	---											
Documentation etc.	*minimal*	*GEN.IMPLIED*	YES											
Training, etc.	*none*	*GEN.IMPLIED*	YES											
			0											

17	6 TS(s) properties to „know-SMQ“ information in the LC stages		&	DIAGRAMS ▶▶
0	***6.1* Suitability for LS (legislative, strategic, ...) management criteria**		Select from	Comparable
0	*•Laws, directives, patents, licenses, binding standards, ...(L), •Org.strategy (product, market,...) (S),*		the menu	for all TS?
0	**• All LC stages:**		---	—
1	*Legislation, obligatory regulations:*	*no violation*	*STATED/ASS.*	YES
1	*Patents and licences*	*no violation*	*OBLIGATORY*	YES
1	*EN ISO 13857 standards for safety of products*	*no violation*	*STATED/ASS.*	YES
0				0
0	***6.2* Suitability for QTC Product-design "know-SMQ" management criteria**		Select from	Comparable
0	*• Product criteria (Q), • Term criteria (T), • Cost criteria (C), etc.*		the menu	for all TS?
0	**• All LC stages:**		---	—
1	*Total number of TS*	*500pcs./year*	*STATED/ASS.*	YES
0	**• Pre-production stages:**		---	—
1	*- time (=> term) of prelim. stage of prototype / first TS*	*10 days*	*OBLIGATORY*	YES
1	*- total costs of pre-production stage of prototype / first TS*	*250000 CZK*	*OBLIGATORY*	YES
1	*- total budget costs for pre-production stages of the next TS*	*150000 CZK*	*OBLIGATORY*	YES
0	**• Production:**		---	—
1	*- time (=> term) for production of prototype / first TS*	*20 days*	*OBLIGATORY*	YES
1	*- total costs of production of prototype / first TS*	*150000 CZK*	*OBLIGATORY*	YES
1	*- total budget costs of production of 1 piece of TS*	*100000 CZK*	*OBLIGATORY*	YES
0	**• Distribution:**		---	—
1	*- time (=> term) to deliver prototype / first TS*	*20 days*	*OBLIGATORY*	YES
1	*- time (=> term) for deliver the next 1 piece of TS*	*10 days*	*OBLIGATORY*	YES
1	*- selling price (competing product approx. 10 000 CZK)*	*cca 12 000 CZK*	*OBLIGATORY*	NO
0	**• Operation:**		---	—
1	*- TS operation costs*	*minimal*	*OBLIGATORY*	YES
1	*- TS maintenance and repair costs*	*minimal*	*OBLIGATORY*	YES
0	**• Disposal:**		---	—
1	*- time to dispose of 1 TS*	*1 day*	*OBLIGATORY*	YES
1	*- the cost of disposing of 1 piece of TS*	*2000 CZK*	*OBLIGATORY*	YES
0				0

(° ÷ ****)	(0 ÷ 4)	(° ÷ ****)	(0 ÷ 4)	(0 ÷ 1)	(° ÷ ****)	(0 ÷ 4)	(0 ÷ 1)	(° ÷ ****)	(0 ÷ 4)	(0 ÷ 1)
***	2	*	2	0,25	*	2	0,25	*	2	0,25

II. DOMAIN of the EMBEDDED TS(s) PROPERTIES - independent of the TS life cycle						SWOT evaluation of initial TS0			SWOT evaluation of comparable TSA			SWOT evaluation of designed TS1		
Properties requirements to TS(s) / TS(s) contract *i Class / i.j Subclass / • Section/Subsection / - indicator*	Value *(quantitative/qualitative) of requirement/property*	Category of the requir. source	Eliminating of evaluat. (& diagrams)	Requir.equival. quality class of indicators	WEIGHT in QP-D	Achieved equiv. quality class of indicators	Evaluation of equival. suitability	WEIGHTed evaluation of eq.suit.	Achieved equiv. quality class of indicators	Evaluation of equival. suitability	WEIGHTed evaluation of eq.suit.	Achieved equiv. quality class of indicators	Evaluation of equival. suitability	WEIGHTed evaluation of eq.suit.
7 TS(s) properties to its constructional structure			DIAGRAMS ►►	(° ÷ ****)	(0 ÷ 4)	(° ÷ ****)	(0 ÷ 4)	(0 ÷ 1)	(° ÷ ****)	(0 ÷ 4)	(0 ÷ 1)	(° ÷ ****)	(0 ÷ 4)	(0 ÷ 1)
7.1 Suitability for the required reactive („general“) TS eng. design properties: *• Mechanical I.: - Macro/mikrosurface, - Macro/microvolumetric, etc.,* *• Mechanical II. - •Strength, - Deformation ,- Dynamic, - Tribological, etc.,* *• Mechanical II. - •Strength, - Deformation ,- Dynamic, - Tribological, etc.,* *• Nuclear, • Chemical-mechanical, • Technological,* *• "Botanic", • "Biological", • "Zoological", apod.*			Comparable for all TS?	****	2	****	3	0,38	****	3	0,38	****	4	0,50
• In sum:		---	---											
Strength at vertical centric load Fv = 150N	*safety to yield streng: sk=3*	OWN	YES											
Lateral stability of the brakedTS at horizont.force on load area Fh=1200N	*safety to overturn: sh=3*	OWN	YES											
			0											
			0											
7.2 Suitability for the required definition („elementary“) TS eng. design properties: ***Constructional structure (in all assumed constructional states!) :*** *•Elements of constructional structutre, •Arrangement of elements* ***Each element of Constructional structure** (in free and assemblied states!)::* *•Forms, •Dimensions, •Materials, •Manuf.ways, •Surf.states, •Deviations from nomin.states:*		Select from the menu	Comparable for all TS?											
• In sum:		---	---											
Structural design of coupling parts	*according to ČSN-EN*	OBLIGATORY	YES											
Surface finish of function surfaces	*high quality*	OBLIGATORY	YES											
Surface finish of nonfunction surfaces	*standard*	OBLIGATORY	YES											
			0											
7.3 Suitability for the required feature TS eng. design properties** („characteristics“):* ***Constructional (structural) features** (execution principles and ways) of TS :* *• Conctructional structure, • Organ structure., • Function structure, etc.* ***Working (function) features of TS: *• Working principle, • Working mode, etc.* ***Technological (transformation) features of TS:*** *•Tg principle & mode, •Principle & mode of the operating technical transform. process* ***General engineering design (mechanical, thermal, chemical, ...) features of TS:*** *• Surface, • Volume • WEIGHT • Position of the center of gravity, apod.*		Select from the menu	Comparable for all TS?											
• In sum:		---	---											
Functional principle	*mechanical*	OWN	YES											
Energy for control and for drive/adjustment	*electrical, mechanical*	OWN	YES											
Source of energy for control and for drive/adjustment	*electrical socket*	OWN	YES											
			0											
$Q_{P\text{-}B}$ PRODUCT-BUSINESS („commercial“) TS(s) CONTRACT QUALITY *- on handover of the TS(s) to the receiving customer (usually to direct user at the end of distribution)*			SUITABILITY diagrams ► DIAGRAMS Q^T^C ►	WEIGHT in QP-M (0 ÷ 4) 4		∑ V.HODNOCENÍ n x (0 ÷ 4) 12,00	V.HODNOC. (0 ÷ 4) 3,00	V.HODNOC. (0 ÷ 1) 0,75	∑ V.HODNOCENÍ n x (0 ÷ 4) 12,00	V.HODNOC. (0 ÷ 4) 3,00	V.HODNOC. (0 ÷ 1) 0,75	∑ V.HODNOCENÍ n x (0 ÷ 4) 12,00	V.HODNOC. (0 ÷ 4) 3,00	V.HODNOC. (0 ÷ 1) 0,75
Requirements to properties (TS(s), contracts TS(s)): *i **Class** / i.j Subclass / • **Section/Subsection** / - indicator*	Value *(quantitative/qualitative) of requirement/property*	Category of the requir. source	Eliminating of evaluat. (& diagrams)	Requir.equival. quality class of indicators	WEIGHT in QP-B	Achieved equiv. quality class of indicators	Evaluation of equival. suitability	WEIGHTed evaluation of eq.suit.	Achieved equiv. quality class of indicators	Evaluation of equival. suitability	WEIGHTed evaluation of eq.suit.	Achieved equiv. quality class of indicators	Evaluation of equival. suitability	WEIGHTed evaluation of eq.suit.
Suitability for PRODUCT-BUSINESS job contract quality, eg.: **• Existing and competitive (comparable) TS (or technical solutions), • Planned number of pieces, etc.**		Select from the menu	Comparable for all TS?	(° ÷ ****)	(0 ÷ 4)	(° ÷ ****)	(0 ÷ 4)	(0 ÷ 1)	(° ÷ ****)	(0 ÷ 4)	(0 ÷ 1)	(° ÷ ****)	(0 ÷ 4)	(0 ÷ 1)
• Distribution:		---	---	***	4	**	3	0,75	**	3	0,75	****	3	0,75
Planned number	*500 pcs./year*	STATED/ASS.	YES											
Distribution network quality	*very good*	OBLIGATORY	YES											
Quality of service security	*very good*	OBLIGATORY	YES											
Brand repute	*very good*	OBLIGATORY	YES											
			0											

T_{P-M} PRODUCT-MARKET ("market") TIME / TERM OT TS(s) CONTRACT - *on handover of the TS(s) to the receiving customer (usually to direct user at the end of distribution)*			SUITABILITY diagrams ▶	WEIGHT in QTCP-M (0÷4)		∑ V.HODNOCENÍ n x (0÷4)	V.HODNOC. (0÷4)	V.HODNOC. (0÷1)	∑ V.HODNOCENÍ n x (0÷4)	V.HODNOC. (0÷4)	V.HODNOC. (0÷1)	∑ V.HODNOCENÍ n x (0÷4)	V.HODNOC. (0÷4)	V.HODNOC. (0÷1)
			DIAGRAMS Q^T^C ▶	4		24,00	3,00	0,75	24,00	3,00	0,75	24,00	3,00	0,75
T_{P-D} PRODUCT-DESIGN („engineering design") TIME / TERM OT TS(s) CONTRACT - *on handover of the TS(s) to the receiving customer (usually to direct user at the end of distribution)*			SUITABILITY diagrams ▶	WEIGHT in TP-M (0÷4)		∑ V.HODNOCENÍ n x (0÷4)	V.HODNOC. (0÷4)	V.HODNOC. (0÷1)	∑ V.HODNOCENÍ n x (0÷4)	V.HODNOC. (0÷4)	V.HODNOC. (0÷1)	∑ V.HODNOCENÍ n x (0÷4)	V.HODNOC. (0÷4)	V.HODNOC. (0÷1)
			DIAGRAMS Q^T^C ▶	4		12,00	3,00	0,75	12,00	3,00	0,75	12,00	3,00	0,75
Properties requirements to TS(s) / TS(s) contract i Class / *i.j Subclass* / • *Section/Subsection* / *- indicator*	Value *(quantitative/qualitative) of requirement/property*	Category of the requir. source	Eliminating of evaluat. *(& diagrams)*	Requir.equival. quality class of indicators	WEIGHT in T_{P-D}	Achieved equiv. quality class of indicators	Evaluation of equivial. suitability	WEIGHTed evaluation of eq.suit.	Achieved equiv. quality class of indicators	Evaluation of equivial. suitability	WEIGHTed evaluation of eq.suit.	Achieved equiv. quality class of indicators	Evaluation of equivial. suitability	WEIGHTed evaluation of eq.suit.
Suitability for PRODUCT-DESIGN times / terms of contract, eg.: • Key partial and total delivery terms (times, event. dates) • Reserves for unforeseen delays, etc. :		Select from the menu	Comparable for all TS?	(° ÷ ****)	(0 ÷ 4)	(° ÷ ****)	(0 ÷ 4)	(0 ÷ 1)	(° ÷ ****)	(0 ÷ 4)	(0 ÷ 1)	(° ÷ ****)	(0 ÷ 4)	(0 ÷ 1)
• Distribution:		---	---	***	4	**	3	0,75	***	3	0,75	***	3	0,75
Max. delivery time (=> term) to protot. / first piece (T1 P-D)	*30 days*	*OBLIGATORY*	YES											
Max. delivery time (=> term) to next piece (T P-D)	*5 days*	*OBLIGATORY*	YES											
			0											
			0											
T_{P-B} PRODUCT-BUSINESS („commercial") TIME / TERM OT TS(s) CONTRACT - *on handover of the TS(s) to the receiving customer (usually to direct user at the end of distribution)*			SUITABILITY diagrams ▶	WEIGHT in TP-M (0÷4)		∑ V.HODNOCENÍ n x (0÷4)	V.HODNOC. (0÷4)	V.HODNOC. (0÷1)	∑ V.HODNOCENÍ n x (0÷4)	V.HODNOC. (0÷4)	V.HODNOC. (0÷1)	∑ V.HODNOCENÍ n x (0÷4)	V.HODNOC. (0÷4)	V.HODNOC. (0÷1)
			DIAGRAMS Q^T^C ▶	4		12,00	3,00	0,75	12,00	3,00	0,75	12,00	3,00	0,75
Properties requirements to TS(s) / TS(s) contract i Class / *i.j Subclass* / • *Section/Subsection* / *- indicator*	Value *(quantitative/qualitative) of requirement/property*	Category of the requir. source	Elimination of indic.ev. *(& diagrams)*	Requir.equival. quality class of indicators	WEIGHT in T_{P-B}	Achieved equiv. quality class of indicators	Evaluation of equivial. suitability	WEIGHTed evaluation of eq.suit.	Achieved equiv. quality class of indicators	Evaluation of equivial. suitability	WEIGHTed evaluation of eq.suit.	Achieved equiv. quality class of indicators	Evaluation of equivial. suitability	WEIGHTed evaluation of eq.suit.
Suitability for PRODUCT-BUSINESS times / terms of contract, eg.: • Key partial and total delivery terms (times, event. dates) • Reserves for unforeseen delays, etc. :		Select from the menu	Comparable for all TS?	(° ÷ ****)	(0 ÷ 4)	(° ÷ ****)	(0 ÷ 4)	(0 ÷ 1)	(° ÷ ****)	(0 ÷ 4)	(0 ÷ 1)	(° ÷ ****)	(0 ÷ 4)	(0 ÷ 1)
• Distribution:		---	---	***	4	****	3	0,75	**	3	0,75	***	3	0,75
Max.distribution time (=> term) - if know (T P-B)	*2 days*	*OBLIGATORY*	YES											
Max. distrib. time (=> term) to prototype / first piece (T1 P-M)	*15 days (if known) T1 P-D + T P-B (in other cases)*	*OBLIGATORY*	YES											
Max. distribution time (=> term) per next piece (T P-M)	*15 days (if known) T P-D + T P-B (in other cases)*	*OBLIGATORY*	YES											
			0											

#	Properties requirements	Value	Category	Eliminating	Requir.	WEIGHT	Σ	V.	V.	Σ	V.	V.	Σ	V.	V.
2 2	**C_{P-M} PRODUCT-MARKET ("market") COSTS/PRICE OF TS(s) CONTRACT** - on handover of the TS(s) to the receiving customer (usually to direct user at the end of distribution)			SUITABILITY diagrams ►	WEIGHT in QTCP-M (0÷4)		Σ V.HODNOCENÍ n x (0÷4)	V.HODNOC. (0÷4)	V.HODNOC. (0÷1)	Σ V.HODNOCENÍ n x (0÷4)	V.HODNOC. (0÷4)	V.HODNOC. (0÷1)	Σ V.HODNOCENÍ n x (0÷4)	V.HODNOC. (0÷4)	V.HODNOC. (0÷1)
				DIAGRAMS Q^T^C ►	4		28,00	3,50	0,88	24,00	3,00	0,75	20,00	2,50	0,63
1	**C_{P-D} PRODUCT-DESIGN („engineering design") COSTS/PRICE OF TS(s) CONTRACT** on handover of the TS(s) to the receiving customer (usually to direct user at the end of distribution)			SUITABILITY diagrams ►	WEIGHT in CP-M (0÷4)		Σ V.HODNOCENÍ n x (0÷4)	V.HODNOC. (0÷4)	V.HODNOC. (0÷1)	Σ V.HODNOCENÍ n x (0÷4)	V.HODNOC. (0÷4)	V.HODNOC. (0÷1)	Σ V.HODNOCENÍ n x (0÷4)	V.HODNOC. (0÷4)	V.HODNOC. (0÷1)
				DIAGRAMS Q^T^C ►	4		16,00	4,00	1,00	12,00	3,00	0,75	8,00	2,00	0,50
	Properties requirements to TS(s) / TS(s) contract i Class / i.j Subclass / • *Section/Subsection* / *- indicator*	**Value** *(quantitative/qualitative) of requirement/property*	**Category of the requir. source**	Eliminating of evaluat. (& diagrams)	Requir.equival. quality class of indicators	WEIGHT in C_{P-D}	Achieved equiv. quality class of indicators	Evaluation of equvial. suitability	WEIGHTed evaluation of eq.suit.	Achieved equiv. quality class of indicators	Evaluation of equvial. suitability	WEIGHTed evaluation of eq.suit.	Achieved equiv. quality class of indicators	Evaluation of equvial. suitability	WEIGHTed evaluation of eq.suit.
nCP-D 2	**Suitability for PRODUCT-DESIGN costs / price of contract, eg.:** • Key partial and total delivery costs (prices), • Reserves for unforeseen costs, etc. :		**Select from the menu**	Comparable for all TS?	(° ÷ ****)	(0 ÷ 4)	(° ÷ ****)	(0 ÷ 4)	(0 ÷ 1)	(° ÷ ****)	(0 ÷ 4)	(0 ÷ 1)	(° ÷ ****)	(0 ÷ 4)	(0 ÷ 1)
0	**• Distribution:**		---	---	***	4	**	4	1,00	***	3	0,75	***	2	0,50
1	*Delivery costs for prototype / first piece (C1 P-D)*	*838.7 €*	*OBLIGATORY*	NO											
1	*Delivery costs for next piece (C P-D)*	*838.7 €*	*OBLIGATORY*	YES											
0				0											
0				0											
1	**C_{P-B} PRODUCT-BUSINESS ("commercial") COSTS/PRICE OF TS (s) CONTRACT** on handover of the TS(s) to the receiving customer (usually to direct user at the end of distribution)			SUITABILITY diagrams ►	WEIGHT in CP-M (0÷4)		Σ V.HODNOCENÍ n x (0÷4)	V.HODNOC. (0÷4)	V.HODNOC. (0÷1)	Σ V.HODNOCENÍ n x (0÷4)	V.HODNOC. (0÷4)	V.HODNOC. (0÷1)	Σ V.HODNOCENÍ n x (0÷4)	V.HODNOC. (0÷4)	V.HODNOC. (0÷1)
				DIAGRAMS Q^T^C ►	4		12,00	3,00	0,75	12,00	3,00	0,75	12,00	3,00	0,75
	Properties requirements to TS(s) / TS(s) contract i Class / i.j Subclass / • *Section/Subsection* / *- indicator*	**Value** *(quantitative/qualitative) of requirement/property*	**Category of the requir. source**	Eliminating of evaluat. (& diagrams)	Requir.equival. quality class of indicators	WEIGHT in C_{P-B}	Achieved equiv. quality class of indicators	Evaluation of equvial. suitability	WEIGHTed evaluation of eq.suit.	Achieved equiv. quality class of indicators	Evaluation of equvial. suitability	WEIGHTed evaluation of eq.suit.	Achieved equiv. quality class of indicators	Evaluation of equvial. suitability	WEIGHTed evaluation of eq.suit.
nCP-B 3	**Suitability for PRODUCT-BUSINESS costs / price of contract, eg.:** • Key partial and total delivery costs (prices) • Reserves for unforeseen costs, etc. :		**Select from the menu**	Comparable for all TS?	(° ÷ ****)	(0 ÷ 4)	(° ÷ ****)	(0 ÷ 4)	(0 ÷ 1)	(° ÷ ****)	(0 ÷ 4)	(0 ÷ 1)	(° ÷ ****)	(0 ÷ 4)	(0 ÷ 1)
0	**• Distribution:**		---	---	***	4	****	3	0,75	**	3	0,75	***	3	0,75
1	*Distribution costs (incl. profit) - if known (C P-B)*	*3000 CZK*	*OBLIGATORY*	YES											
1	*Max. deliv. costs (price) for prototype / first piece (C1 P-M)*	*18 000 CZK (if known) C1 P-D + C P-B (otherwise.)*	*OBLIGATORY*	YES											
1	*Max. deliv. costs (price) for next piece (C P-M)*	*13 000 Kč (if known) C P-D + C P-B (otherwise)*	*OBLIGATORY*	YES											
0				0											

Legend

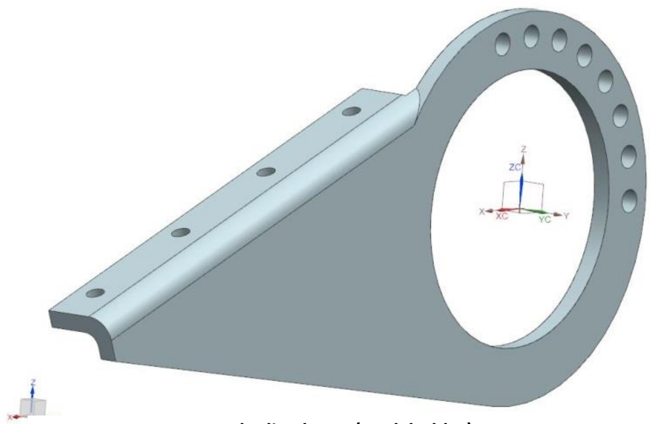
For more see eg. Hosnedl S .: System design of technical systems. Materials for lectures KKS / ZKM. Pilsen: UWB, FST, KKS. 2019.

Selected basic abbreviations and terms:			
TS :	***Technical product understood as a technical system***		
TS (s)	***"Subjected technical system (TS)"*** *which is the subject of the task under consideration (here specification requirements and assessment of suitability and competitiveness), distinguished from all other TS*		
Competitive TS (s)	***Other comparable, alternative, etc. TS (s)*** *(or comparable "technical solution" if a competing TS (s) is not known or does not exist)*		
P-DESIGN, P-D	***PRODUCT-DESIGN:*** *designation of "design" evaluation criteria of (contract) TS (s) depending only on the "inseparable" (imherent) properties of TS (s) (assuming "design situations" including limitations !!!) without consideration of "business" factors* ***- eg. "design" requirements, characteristics, suitability, quality, competitiveness, etc.***		
P-BUSINESS, P-B	***PRODUCT-BUSINESS:*** *designation for "business" evaluation criteria of (contracts) TS (s) also dependent on other assigned factors / "properties" TS (s)* ***- eg. "business" requirements, characteristics, suitability, quality, competitiveness, etc.:***		
P-MARKET, P-M	***PRODUCT-MARKET:*** *designation for "market" evaluation criteria of (contracts) TS (s) depending on ROPRODUCT-DESIGN (inherent) and PRODUCT-BUSINESS (assigned) factors* ***- eg. "market" requirements, characteristics, suitability, quality, competitiveness, etc.***		
SMQ	***Six Management Questions: what*** *to make* ***? , when? , where? , how ? , in what quantities ? , with what inputs ?***		
Σ	***In the transferred meaning "result value", "set of items", etc., not in the mathematical meaning "sum" (numerical values, etc.) !!!***		
Designation of category of source of criterion - of request *(per property, property indicator, etc.) and automatic color highlighting of fields for the two most important request categories*			
STATED	*Entered, egreeded*	*(Stated)*	*- highlighting of a great commitment, it is difficult to change subsequently (by agreement, etc.)*
OBLIGATORY	*Mandatory, prescribed*	*(Obligatory)*	*- highlighting of unconditional obligation, cannot be changed*
GEN. IMPLIED	*Usually predicted*	*(Generally Implied)*	*- expressing of less obligation, can be influenced (eg. by marketing, etc.)*
OWN	*Own*	*(Own)*	*- expressing of less obligation, can be changed*
The recommended scale of expression using characters *[ISO-9000 2016]* ***(required or actual / predicted) of the "quality class" criteron (if underlined, refers to the criteria for assessing the suitability of TS (s) for all specified requirement s;otherwise only the criteria for evaluation of mutual competitiveness of TS (s))***			
**** | ****	*Maximal*	*level*	
*** | ***	*Medium*	*level*	
** | **	*Small*	*level*	
* | *	*Minimal*	*level*	
° | *	*Negligible*	*level*	
X | X	*Unknown*	*level*	
Recommended scoring of the weight of the criterion (ie. its significance within the given group of criteria), *or assessment of suitability (ie, relation of values) of the predicted / actual and desired state or (underlining or non-underlining has the analogous meaning as at the expressing of the "quality class" criterion):*			
4 | 4	*Maximal*	*importance, suitability*	
3 | 3	*Medium*	*importance, suitability*	
2 | 2	*Small*	*importance, suitability*	
1 | 1	*Minimal*	*importance, suitability*	
0 | 0	*Negligible*	*importance, suitability*	
0 | 0	*Unknown*	*importance, suitability*	*- pokud není známá ani posuzovaná hodnota , vyjádřete ji písmenem " n " a barva pole se odliší šedě:*
Signal designation of fields with analyzes results *(for suitability evaluation can be set the relative limit values in the cells U3 and X3 on this sheet)*			
value	*Out of limit values in the "danger" zone*		
value	*Between min. and max. limit value, ie in the "safe" zone*		
value	*Out of limits in the "too safe" zone*		

Appendix no. 3

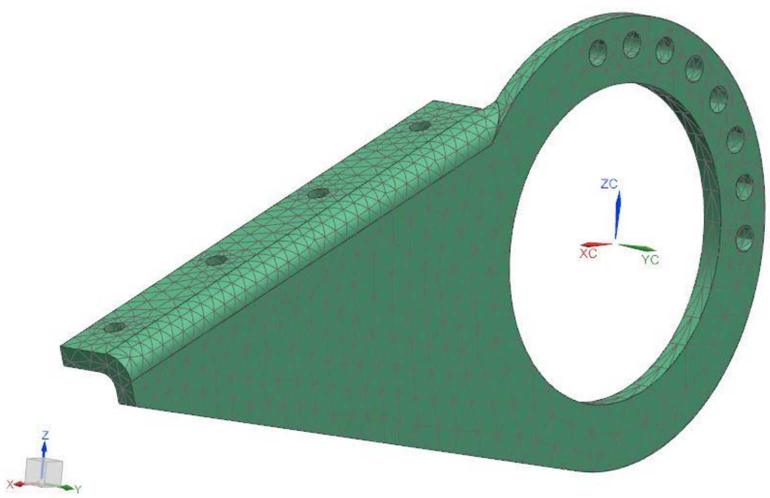
FEM analysis of the desk holder

The desk holder is a component of the conveyor used to support the sliding desk and also to attach this desk to the conveyor. This part is placed on the powered roller holder and attached by a bolt to it.



Idealised part (Desk holder)

In the picture above, there is shown the idealised body of the component. This idealised component is almost the same as the real component, there were deleted just some unwanted chamfers and radiuses.

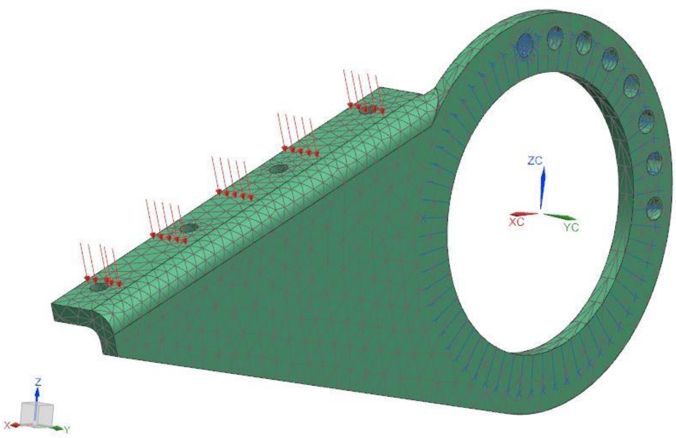


Meshed model (Desk holder)

Desk holder	
Selected options	
Type of the mesh:	3D Tetrahedral Mesh
Type of the element:	CTETRA(10)
Size of the element:	6
Material:	Steel

Desk holder (mesh properties)

In the picture above is shown meshed idealised part. The selected properties of this mesh are shown in the table above.

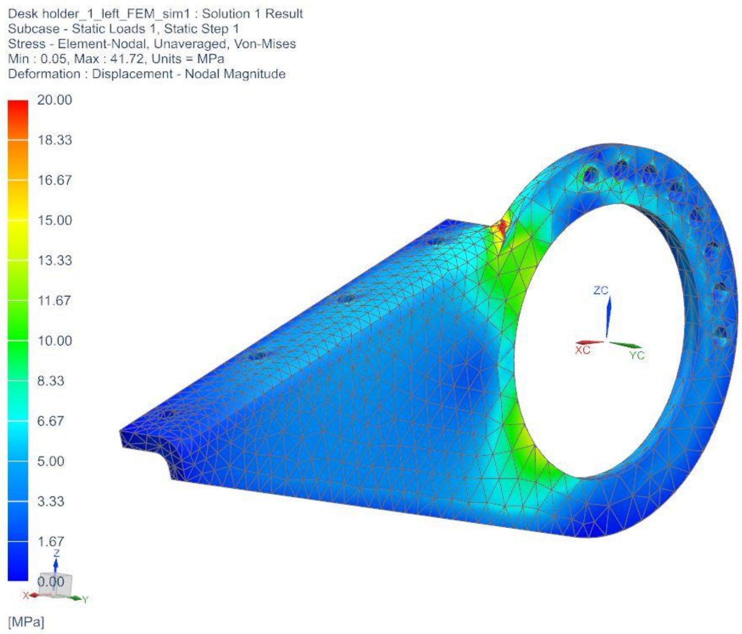


Loads and constraints applied on the model (Desk holder)

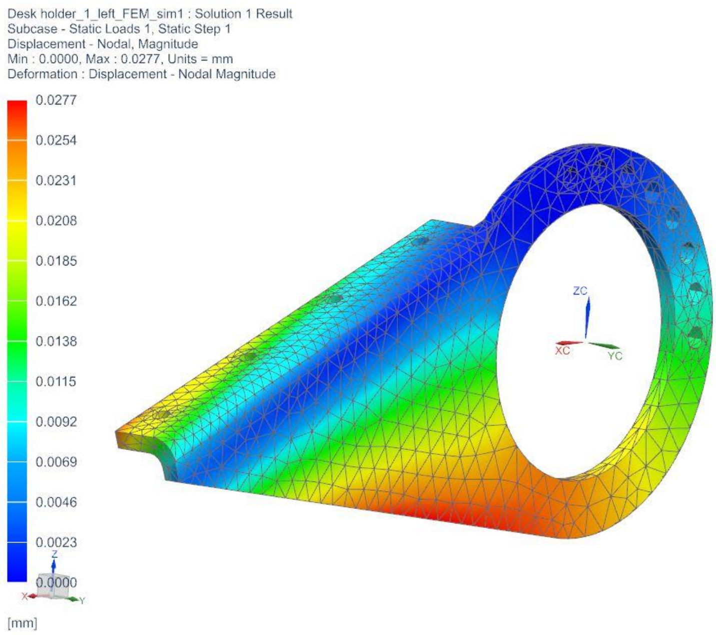
In the picture above is shown meshed part with highlighted the loads and constraints. In this case, is the part loaded by one force F1 which is placed on the upper part (where the desk is attached) and it replaces mass of the maximal product placed on the sliding desk. It has to be taken into account that this force is just replacing half of the mass of the product because there are two holders used to attach the sliding desk. The large hole inside the holder which is used to attaching the holder to the powered roller holder is constrained by cylindrical constraint fixed in radial growth. The next constraint is placed in the hole for the locking bolt and fixed in all directions.

Forces applied on the desk holder	
Selected options	
F1	150 N

Loads applied on the model (Desk holder)



RESULTS: Stress - Element - Nodal (Von-Mises)



RESULTS: Displacement - Nodal

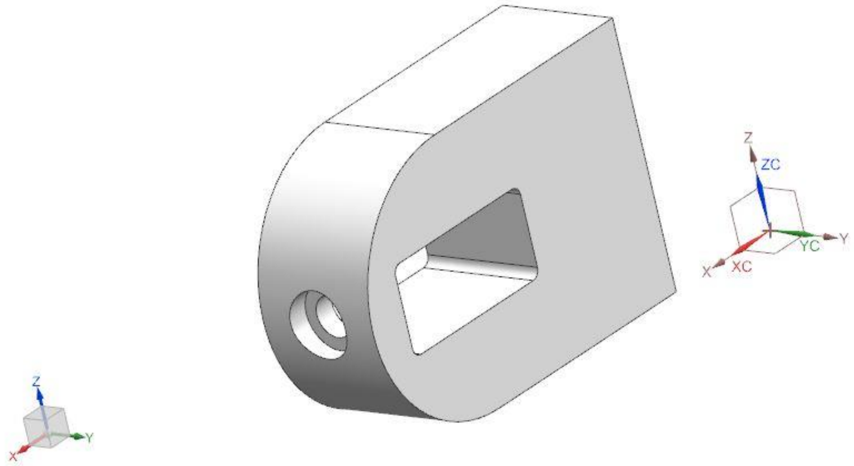
In the pictures above are visible results from the solution. The maximal stress in this part is 41.72 MPa. This stress is located in the corner where the radius passes into the plane. In the real situation, it has to be considered that this stress should be reduced because of the attachment of the desk on both sides (the holder will not bend in –Y direction). Nevertheless, this maximal stress is still acceptable.

The maximal displacement founded in this part is 0.0277 mm. This displacement is minimal (especially for the thin-walled product), and it is acceptable.

Appendix no. 4

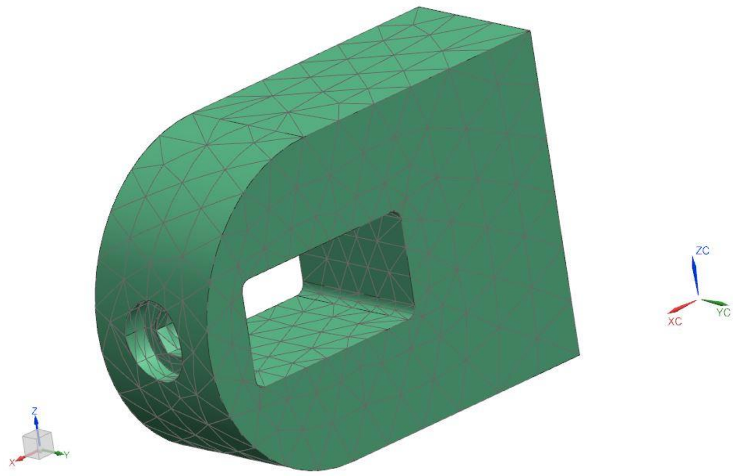
FEM analysis of the back roller holder

The back roller holder was designed to carry the back roller and also to enable adjusting of the roller.



Idealised part (Back roller holder)

On the picture above is shown the idealised body of the component. There were deleted holes for locking bolts to the frame of the conveyor.

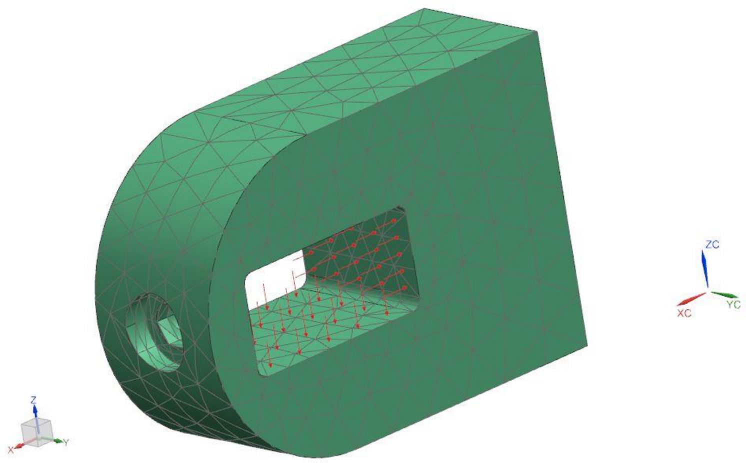


Meshed model (Back roller holder)

Back roller holder	
Selected options	
Type of the mesh:	**3D Tetrahedral Mesh**
Type of the element:	**CTETRA(10)**
Size of the element:	**10**
Material:	**Aluminum_2014**

Back roller holder (mesh properties)

In the picture above is shown meshed idealised part. The selected properties of this mesh are shown in the table above.

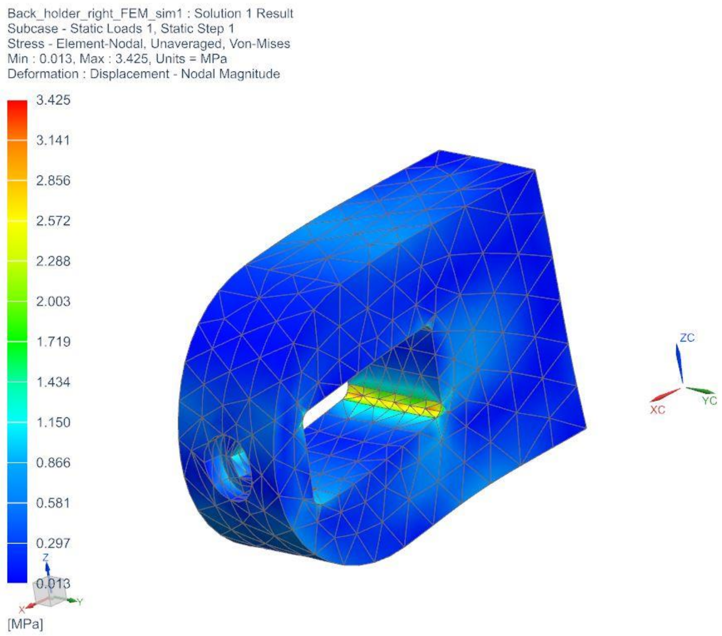


Loads and constraints applied on the model (Back roller holder)

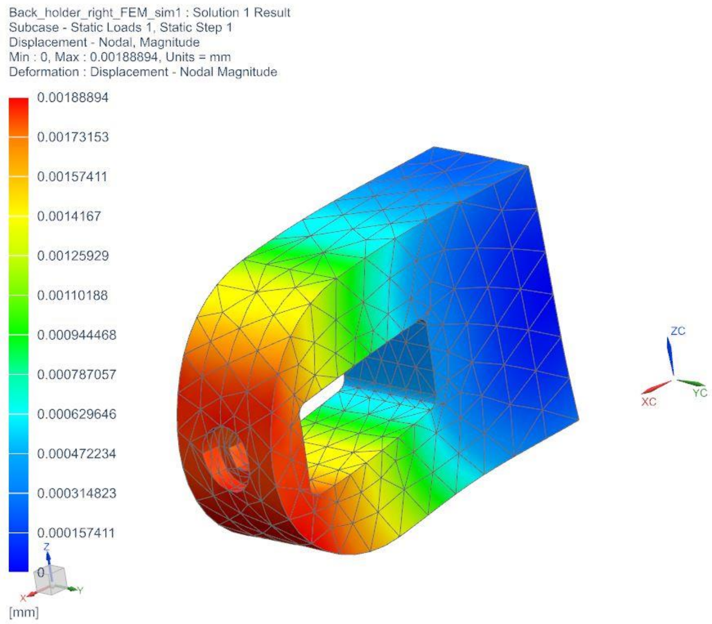
This part was loaded with forces F1 and F2. The first force F1 is the tensional force which is placed on the backside of the cutout for the rollers shaft. The second force F2 is replacing the mass of the back roller, and of course, the mass of one maximal product placed on the corner of the belt conveyor, because of the needs for the critical load was this force multiplied with few percents. This force is placed on the bottom of the cutout for the shaft.

Forces applied on the back roller holder	
Selected options	
F1	**63 N**
F2	**200 N**

Loads applied on the model (Back roller holder)

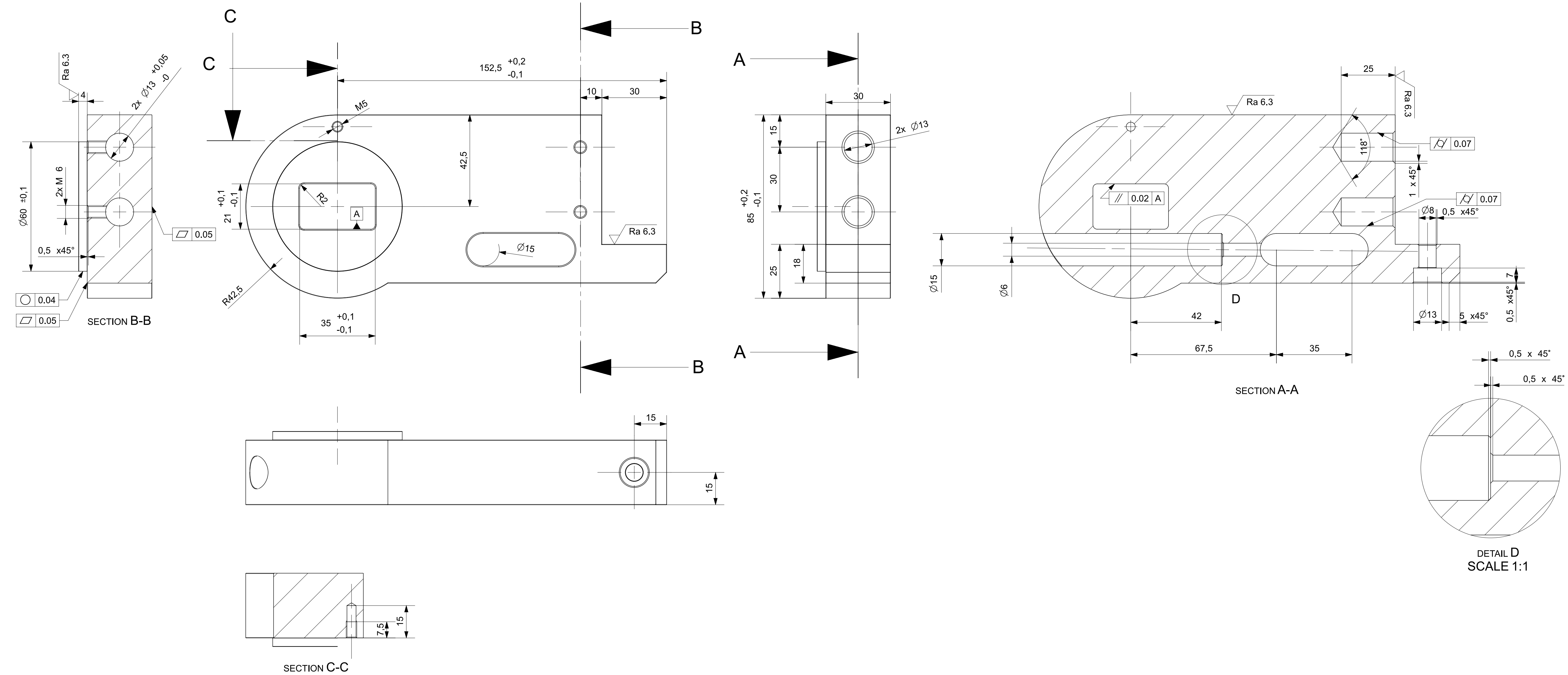


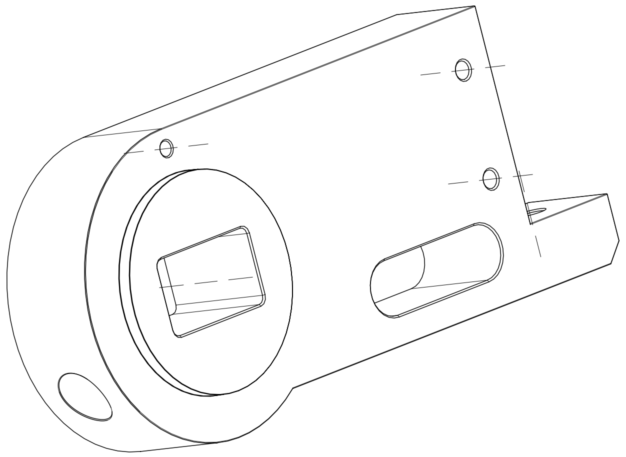
RESULTS: Stress - Element - Nodal (Von-Mises)

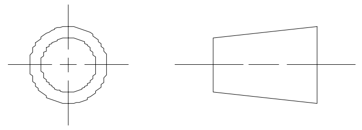


RESULTS: Displacement - Nodal

On the last two pictures (above) are displayed results from the FEM analysis. The maximal stress in this component is 3,425 MPa, and that shows how insignificant is the stress in this component. The following result is maximal displacement (deformation) on this component, and the value is 0,00189 mm, and that is also insignificant value for this solution.







(Ra 3.2) UN DIMENSIONED RADII : R0,2

ALL DIMENSIONS IN MM

PC NO	PART NAME	CURRENT NAME	BLANK	START/END MATERIAL	C.W.	MASS	R.WEIGHT	DRAWING NO.	QTY

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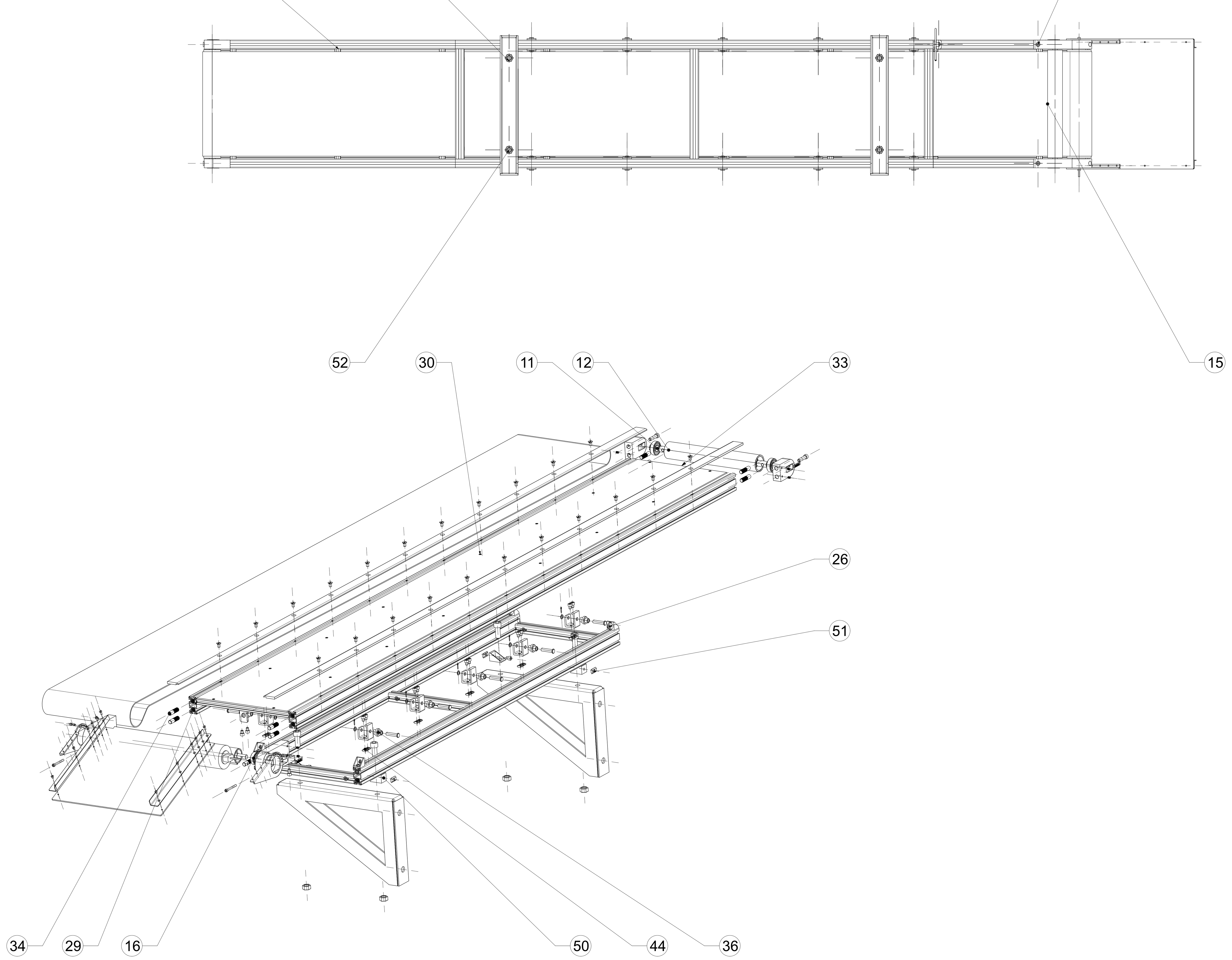
TEMPLATE PROVIDED BY SIEMENS PLM SOFTWARE

FIRST ISSUED	TOMÁŠ BLÁHA	TITLE
DRAWN BY		POWERED ROLLER HOLDER
CHECKED BY		
APPROVED BY		SIZE A3 · DRG NO. DRW-00-00-01 · SHEET REV A
		SCALE 1:2 · SHEET 1 OF 1

A3



PC NO	PART NAME	CURRENT NAME	BLANK	START/END MATERIAL	C.W.	MASS (grams)	R. WEIGHT	DRAWING No.	QTY
58	NUMERAL_STRING	Measuring label	-	-	-		-	-	4
57	SCREWM8X10	Bolt M8 x 10	-	-	-		-	-	22
56	COVERING_LINES	Covering side ledge	-	-	-		-	-	2
55	BELT_CONVE	PVC belt	-	-	-		-	-	1
54	SCREW_M8X15	Bolt M8 x 15	-	-	-		-	-	2
53	NUT_M16	Nut M16	-	-	-		-	-	4
52	SCREW_M16X40	Bolt M16 x 40	-	-	-		-	-	4
51	CONNECTOR_25	Connector (w,spring, F M6 L25)	-	-	-		-	-	6
50	WINGL_STEEL	Steel angle	-	-	-	82,3	-	-	4
49	SCREWM5X6	Bolt M5 x 6	-	-	-	1,7	-	-	4
48	SCREWM5X11	Bolt M5 x 11	-	-	-		-	-	8
47	SCREW_M5X15	Bolt M5 x 15	-	-	-		-	-	2
46	SCREW_M10X40	Bolt M10 x 40	-	-	-		-	-	2
45	SCREW_M8X10	Bolt M8 x 10	-	-	-		-	-	26
44	CONNECTOR_15	Connector (w,spring, F M6 L15)	-	-	-		-	-	44
43	LOCKING_PIN	Safety lock - pin	-	-	-		-	-	1
42	LOCKING_PART	Safety lock - body	-	-	-		-	-	1
41	SAFETY_CONVEYOR_LOCK_STICK	Safety lock - stick	-	-	-	47,2	-	-	1
40	E_R_HOLDER	Ejecting roller holder	-	-	-	138,3	-	-	10
39	BOLT	Pin ∅ 10	-	-	-	31,3	-	-	10
38	WASHER_E_R	Washer ∅ 10	-	-	-	0,8	-	-	10
37	SPLIT_PIN_E_R	Split pin ∅ 2,5	-	-	-	0,8	-	-	10
36	EJECTING_ROLLER	Ejecting roller	-	-	-	49,0	-	-	10
35	SCREW_M6X9.5	Bolt M6 x 9,5	-	-	-	1,8	-	-	8
34	CONNECTING_STICKS	Holder connector	-	-	-	49,2	-	-	8
33	1.85.040-99X360.00X2720.00-(3)	Supporting desk (360 x 2720 x 4)	-	-	-	30656,5	-	-	1
32	1.11.030060.64LPX2720.00(2)	Upper frame side (30 x 60 x 2720, 6F, LP)	-	-	-	12046,6	-	-	2
31	1.10.020020.43LPX368.00(1)	Upper frame strut (20 x 20 x 368, 4H, LP)	-	-	-	497,4	-	-	8
30	0.63.D07991.04008	Bolt M6 x 10	-	-	-	1,0	-	-	16
29	1.20.2F0	Universal MayTec connector (20 x 20)	-	-	-	12,2	-	-	16
28	SUPPORTING_CONSOLES	Supporting console	-	-	-	5868,7	-	-	2
27	0.63.WN7381.06010	Bolt M6 x 10	-	-	-	4,2	-	-	4
26	0.61.D00439.06	Bolt M6 x 15	-	-	-	2,7	-	-	4
25	1.32.4FM6	Connector (w,spring, F M6)	-	-	-	5,1	-	-	4
24	1.21.3F0	Universal MayTec connector (30 x 30)	-	-	-	52,1	-	-	6
23	1.11.030030.43LPX368.00(1)	Lower frame strut (30 x 30 x 368, 4F, LP)	-	-	-	900,3	-	-	3
22	1.11.030060.64LPX1600.00(2)	Lower frame side (30 x 60 x 1600, 6F, LP)	-	-	-	7088,1	-	-	2
21	1.66.8060	Rubber stop	-	-	-	19,2	-	-	4
20	0.63.D06912.06016	Bolt M6 x 12	-	-	-	5,5	-	-	4
19	1.46.204.2828.1	Gusset 28 x 28, nat.	-	-	-	53,1	-	-	4
18	TENSION_BOLT	Adjusting bolt	-	-	-	15,7	-	-	2
17	T_R_SHAFT	Adjusting roller shaft	-	-	-	1028,0	-	-	1
16	W 6302-2Z_STP	W 6302-2Z	-	-	-		-	-	2
15	T_R_BODY	Adjusting roller	-	-	-	3148,2	-	-	1
14	SAFETY_RING	Retaining ring ∅ 15	-	-	-	0,7	-	-	2
13	B_R_SHAFT	Back roller shaft	-	-	-	1475,8	-	-	1
12	BACK_ROLLER	Back roller	-	-	-	3005,4	-	-	1
11	6204-2RSL_STP	6204-2RSL	-	-	-	-	-	-	2
10	B_R_B_HOLDER	Retaining ring ∅ 20	-	-	-	1,9	-	-	2
9	BACK_HOLDER_RIGHT	Back roller holder	-	-	-	319,2	-	-	2
8	02201-4417_001 - MTR GEAR 0.075KW BELT DRIVE 80S 362L	Electric motor	-	-	-	14900,5	-	-	1
7	DESC_CORNER _LEFT	Desk corner (Right)	-	-	-	279,8	-	-	1
6	DESK HOLDER_1_LEFT	Desk holder (Left)	-	-	-	236,1	-	-	1
5	DESK_1	Sliding desk	-	-	-	5227,4	-	-	1
4	DESC_CORNER	Desk corner (Left)	-	-	-	279,4	-	-	1
3	DESK HOLDER_1_RIGHT	Desk holder (Right)	-	-	-	236,1	-	-	1
2	ROLLER_HOLDER_LEFT_2	Powered roller holder (Left)	-	-	-	929,2	-	DRW-00-00-01	1
1	ROLLER_HOLDER_RIGHT_2	Powered roller holder (Right)	-	-	-	934,2	-	-	1

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FIRST ISSUED	TOMÁŠ BLÁHA	TITLE
DRAWN BY		BELT CONVEYOR - ASSEMBLY
CHECKED BY		
APPROVED BY		

SIZE	DRG NO.	SHEET REV
A1	DRW-00-00-00	A
SCALE 1:10		SHEET 1 OF 5

ALL DIMENSIONS IN MM