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The effect of feed drive axes dynamics on the wearing of linear guideways

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1. Introduction

This paper treats a method developed by the authors which helps to evaluate loading linear guideways used in NC machine tools. Research was motivated by the industrial problem with total damage of linear guideways which occured during the high productive manufacturing of small parts. Method links two mechanical influences on failure of linear guideways. The count of contacts between the guideway static part (rail) and its moving part (bearing block) alongside the rail and the level of acceleration at these points. Method facilitate insight into non-constant load of linear guideway alongside its rail and takes into accounts the influence of dynamics of all three feed drive axes X, Y and Z on axis X where damaging occurs. Method helps to find appropriate set of maximal accelerations and jerks of feed drive axes X, Y and Z with lower dynamic impact on the load of guideway and with minimal penalty on machining time.

2. Outline of the problem

Fig. 1 (left) shows schema of linear guideway commonly used in machine tools. It consists of rail, bearing block and rolling element which could be ball shaped or roller shaped. In our case roller type was used. Bearing block is filled by a long life grease and equipped by seal elements to wiping down chips from machining. Damaged locations on rails are marked by the red points. Our task was to clarify the causes of damage of linear guideways used in highly productive production of duralumin parts. Two significant influences with impact on linear guideways damage were supposed. Malfunction of greasing and impact of inertial forces given by frequent acceleration and deceleration of moving axes. Both flows from extreme conditions during the part production. Cycle time of one machined part was approx. 4.5 minutes and machine was used in three-shift operation seven days in week. For the complete machining of part several tools were used. Tool changes requires fast movements to a magazine located at the back end of Y-axis (Fig. 3). Inertial and frictional forces from rapid feeds such causes additional stress to linear guideways beside the cutting forces and inertial forces from machining. Workpiece was machined under intensive flow of cooling emulsion.

3. Causes of linear guideways damage

Damaged sides of rails are shown in Fig. 1 (right). Case A shows constant wear, case B shows wear with surface fatigue but cases C and D show sharply bounded traces from rolling elements of bearing block. Inside the bearing block high degradation of seals and mixture of metal

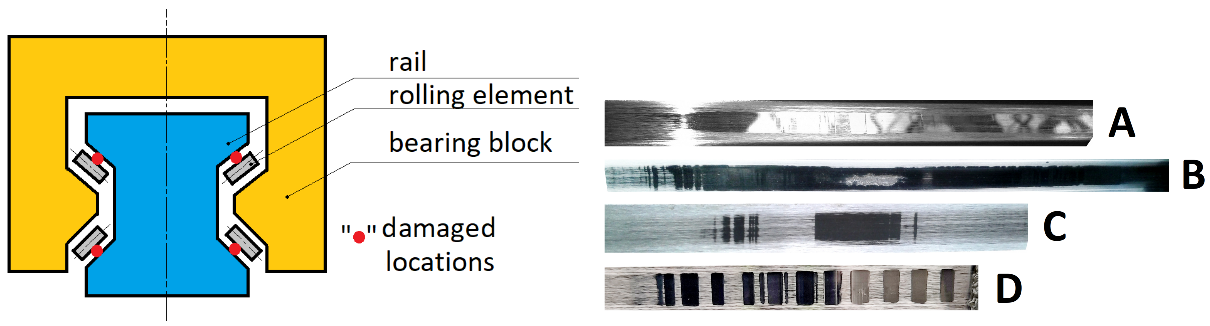

Fig. 1. Schema of linear guideway (left); damaged sides of rails (right)

chips with grease were observed. Such conditions complicate soft movement and causes further damage rollers and rails.

By this hypothesis it would be possible to interpret flat regular traces in cases A and B but short sharp, regular and relatively deep traces in cases C and D would suggest rather local force shocks. It would agree with previously noted dynamical conditions of Y-axis movement. Therefore evaluation method was based on analysis of mechanical loading from inertial forces. Many research topics related to linear guideways from the view in many aspect were published, for example experimental analysis of the wear coefficient [4], effect of grease characteristics on sound and vibration [1] or model for wear prediction [3]. Analysis of drive dynamics is in [2].

4. Graphical evaluation of influence of moving axes dynamics on linear guideways loading

Presented analysis is based purely on processing of data acquired from NC machine tool control system by its internal oscilloscope. Data for analysis are recorded as desired and real positions and velocities of feed drive axes X, Y and Z. Accelerations of axes was computed by a numerical derivation of velocities. Even though proper approach would be based on computation with forces which directly impact on wear of linear guideways only computation with axes accelerations is done. The reason is that no information about moving masses and position of center of gravity is available. So, computations with forces are imitated by computation with accelerations.

Some locations on rails were more damaged than other. This led to examine acceleration not only in time domain but also in geometrical domain along the rail. Moreover, during the working cycle some locations could be in more numerous contact between rail and bearing block than others. Count of appearance on particular coordinate is therefore taken into account by a histogram plot.

So, level of acceleration along the rail forms first 2D graph for identification where local extremes of acceleration acts (top set of Fig. 2). Count of accelerations at the partial rail points forms second 2D graph for identification how many contacts between bearing block and rail was done during the working cycle (middle set of Fig. 2). Both graphs jointed together form 3D histogram with position of particular machine axis on one axis acceleration on second axis and count of acceleration on partial rail point on third axis. For better readibility, 3D graph is converted to 2D where the third axes is represented by the color scale (bottom set of Fig. 2). Let us note the graphs that count of contacts between both parts of guideway was evaluated at 5 mm sections as a summation of values inside this interval (comparisons of histograms for counts on elementary points and for 5 mm ones are for respective axes in middle row of Fig. 2).

The most damaged guideways were on Y-axis where the high exposure of coolant and acceleration frequency from rapid feed acts together. For example, during the working cycle of

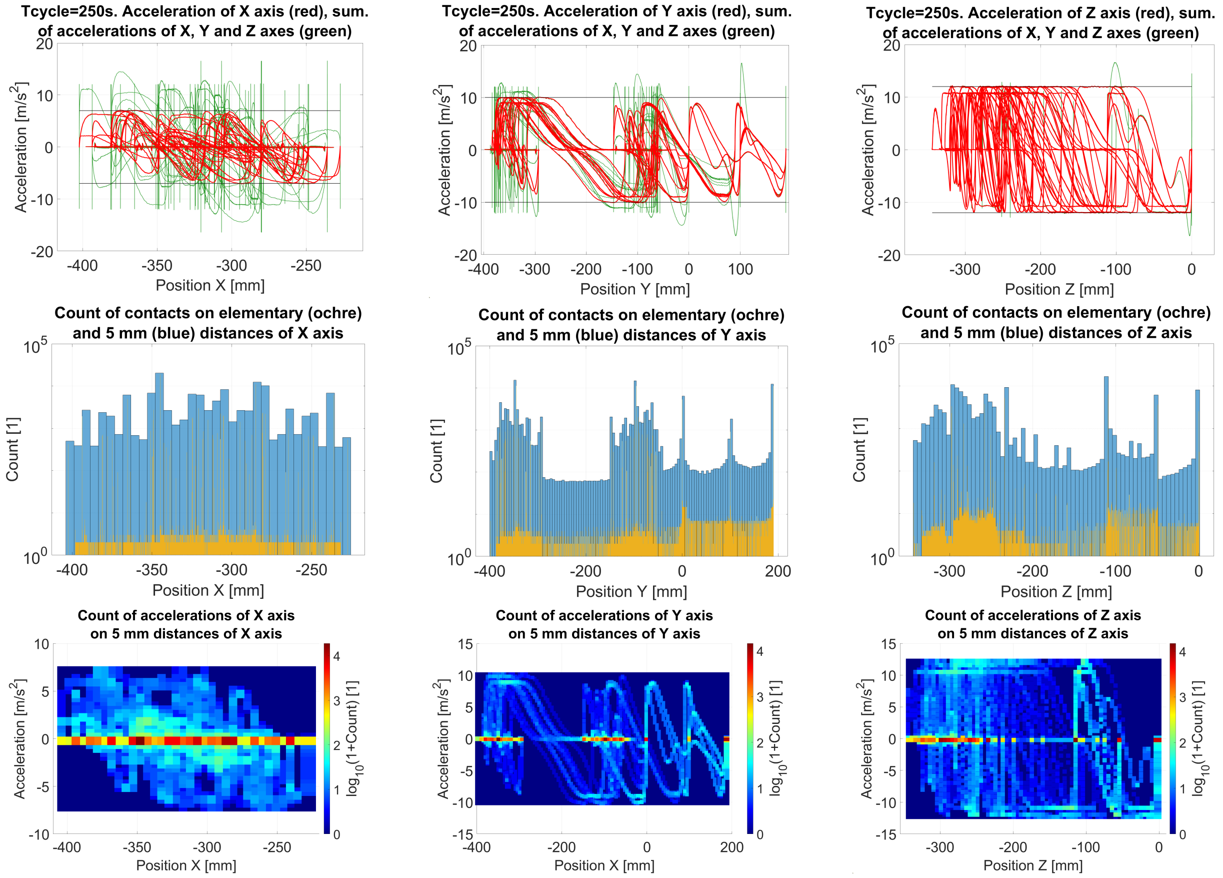

Fig. 2. Level of acceleration along rail (top row); count of acceleration at partial rail points (middle row); 3D histograms count of acceleration on partial rail distances (bottom row). Axes X, Y and Z are grouped in respective columns. Limit of axes accelerations are 7 m/s^2 for X, 10 m/s^2 for Y and 12 m/s^2 for Z, maximal axes jerks are 25 m/s^3 for X, 50 m/s^3 for Y and 300 m/s^3 for Z. Machining time is 250 s

250 s more than 30 accelerations (or decelerations) were to a maximum speed of 75 m/min. For this reason the main attention is paid to the analysis of Y-axis.

Fig. 3 shows a diagram of the machine in the YZ plane. From the figure, it is clear that the forces from the acceleration of Y-axis, together with the forces from acceleration in the Z-axis, create a tilting moment Mx around the X-axis. This causes stress on the guideways of Y-axis.

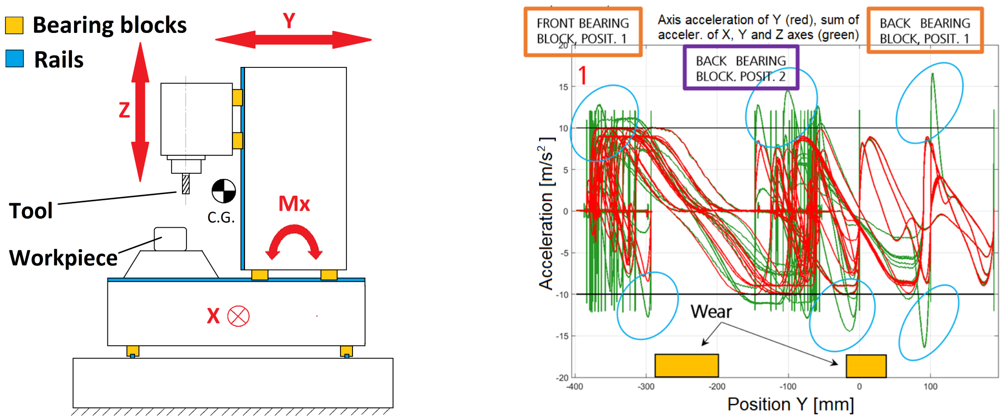

Fig. 3. Schema of machine with coordinates (left); correlation of acceleration extremes with damaged rail sections on Y-axis (right)

Therefore, in Fig. 2 (top row), two acceleration values are plotted. Reds are the accelerations in a given axis and greens are the summations of accelerations in the X, Y and Z axes which together contributes to the loading of guideways. Black lines on graphs in Fig. 2 (top row) shows limit values of axes accelerations. It can be seen that sum of accelerations significantly overlaps limit values for axes X and Y. This imply the influence of other axes to particular axis which results to high forces acting to the guideway. Moreover, histograms from the middle and bottom rows shows that contacts in the Y and Z axes are less regular than in Y-axis. Color maps further detects that higher levels of accelerations are concentrated at particular coordinates. It would clarify why are rails such damaged at these coordinates. Detail graph with correlation of acceleration extremes with damaged rail sections on Y-axis is in Fig. 3 (right).

Based on these analysis several measurements with different accelerations and jerks of axes X, Y and Z were evaluated and the most proper one, also with regard to minimal time penalty, was appicated into the control system of real NC machine tool. This set is graphically shown in Fig. 4. It is clear that sum of the accelerations X, Y and Z axes has lower level and more regular character then in the previous case. Local extremes which probably cause sharp traces on rails diminish.

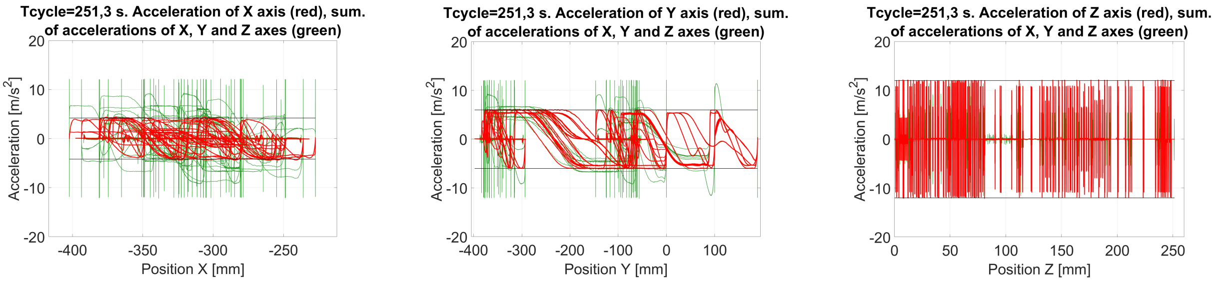

Fig. 4. Optimal set of axes accelerations and jerks with limits 4.2 m/s^2 for X, 6 m/s^2 for Y and 12 m/s^2 for Z, maximal axes jerks are 25 m/s^3 for X, 50 m/s^3 for Y and 300 m/s^3 for Z. Machining time is 251.3 s

5. Conclusions

Primary cause of linear guideway damage was probably influence of cooling emulsion which degrades seal and originate mixture of grease and metal chips which significantly gets worse friction in linear guideways. Another cause of guideways damage sources from high force shocks given by accelerating of all three axes in one moment. Analysis shown relativelly high influence of dynamics of neighbouring axes Z and X to the load of axis Y. Developed analysis brings results which correlates level of accelerations with damaged sections on the rails. More suitable levels of axes accelerations and jerks were chosen and applied into the NC machine tool in industry.

References

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