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Bartosz POWAŁKA[1]
Tomasz OKULIK[1]

INFLUENCE OF APPLICATION OF SPECIAL CASTING COMPOUND ON DYNAMIC CHARACTERISTICS OF THE GUIDEWAY SYSTEM

The work presents a new technology for the assembly of ball guideway systems which involves the use of a thin layer of special casting compound (EPY resin) used mainly for stable seating of machinery, especially on steel or concrete foundations. The paper presents results of simulation investigations. Simulation model was built using results of static tests. The results of simulation dynamic tests in the form of frequency response functions are shown. Experimentally supported simulation research presented in the work indicates that the use of EPY resin between the guide rail and the bed of the machine tool positively influences the dynamics of the system. The comparison of the new solution with the one used so far was performed on the basis of a guideway combination consisting of a body and a milling table. The dynamics was compared with the use of a frequency response function obtained using an impulse test. The proposed solutions are characterized by higher dynamic stiffness, which may directly influence the precision of the machined surfaces.

1. INTRODUCTION

Linear ball guideways, which are now being used more often in modern cutting tools, begin to replace the previously used slide guideways. A considerable disadvantage of the slide guideway systems was the stick-slip phenomenon occurring while machining at a low feed rate [1,7], which contributed to deterioration in the accuracy of the machine tool positioning. The use of ball guideways eliminated this phenomenon. The use of ball guideway systems improved the operating properties of the machine tool body system by reducing the resistance to motion and increasing the permissible feed speed as well as simplifying the assembling technology in comparison with the slide guideway system. However, the main disadvantage of the ball guideway system is the occurrence of low damping.

Machine tool constructors have tried to improve the dissipation parameters of the machine tool body system in various ways. One of the solutions applied in the construction of the machine tool body system is using additional elements made of polymers [2,5] or using a mixture of aggregate, sand and resins [6].

[1] West Pomerania Universitet of Technology, Szczecin, Poland

Producers of guideway systems are constantly aiming at improving the operating properties. Their work is developing in three directions. The first one involves increasing the precision of the guideway system motion [4]. The second development direction involves improving the stiffness properties [8]. The third direction involves increasing the dissipation properties, which is done by using pads of polymers for the construction of the guide carriage [10].

In order to reduce the production costs and increase the dissipation properties of the machine tool body elements a new idea appeared to use a layer of the EPY casting resin [3] between the body elements and the guide rail. The research on the possible use of the resin layer of various thickness was presented in work [9]. This work presents the simulation research on a milling table model, which compared the present technology for assembling the guideway system with a new solution making use of a thin layer of EPY resin for assembling the guideway system. The results obtained from the simulation research indicate a positive influence of using EPY resin on dynamic stiffness of the machine tool. The simulation results are confirmed experimentally. The results are shown in chapter four. The experimental research makes use of the modal test.

2. THE SIMULATION MODEL

The milling table simulation model was made in the convention of the rigid finite elements method. The milling table together with the workpiece were modelled with the use of one finite element. The table mass assumed for the model was 600 kg while the workpiece mass was 400 kg. The stiffness parameters of the lead screw and the ball carriages were modelled with the use of elastic-damping elements and the relatively low damping of the ball carriages was disregarded. The stiffness-dissipation parameters of the contact layer in the contact place between the guide rail and the bed were taken from paper [10]. Fig. 1 presents the simulation model.

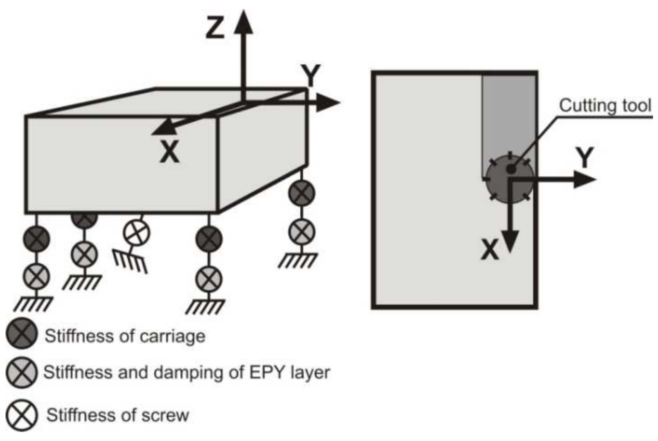

Fig. 1. Schema of the milling table simulation model

The milling table simulation model was excited by a cutting force changing in time corresponding to the milling of the X-Y plane with the use of a milling cutter with the following parameters: cutting depth 4 mm; number of tool blades 8; milling cutter working angle 180º. The rotational speed of the tool was chosen in such a way that the model would be excited in the resonance area for direction Y. Direction Y was chosen for the analysis of the system behaviour because in this direction the stiffness-dissipation parameters of the contact layer decide on the dynamics to the largest extent.

The milling table simulation research was conducted for two models differing in the way of assembling the guide rails. The stiffness-dissipation parameters of the contact layer implemented in the first simulation model corresponded to the presently used technology for assembling the guide rails (steel-steel contact on the ground surface). For this model the spindle rotational speed was 3225 RPM. Since the 8-teeth cutter was assumed in the simulation the tooth frequency was 430 Hz that corresponds to the frequency of the dominant resonance of the model in Y direction. The second model used in the simulation had the stiffness-dissipation parameters implemented for assembling the guide rails on a thin layer of EPY resin (EPY resin-steel contact). In this variant the bed surface was milled and the resin layer was 0 mm thick. The 0 mm thickness is to be understood as a thin layer of resin, on which the guide rail was founded and then screwed with a proper torque at the same time squeezing the surplus of the EPY resin out of the connection. Eventually, EPY resin filled only the irregularities of the assembly surface resulting from rough machining. For this model, the tool rotational speed was set in the similar manner, i.e. the tooth frequency was equal to the frequency of the dominant resonance.

The workpiece machining precision is influenced by the relative displacements between the workpiece and the tool in the tool working point. Fig. 2 presents the amplitude of displacement obtained from numerical simulations for a model based on the presently used technology of assembling guide rails. A dominant amplitude of displacement can be noticed on the graph for direction Y while the displacements in the other directions are relatively small. For this model, the amplitude of vibration for direction Y has the level of about 11 μm.

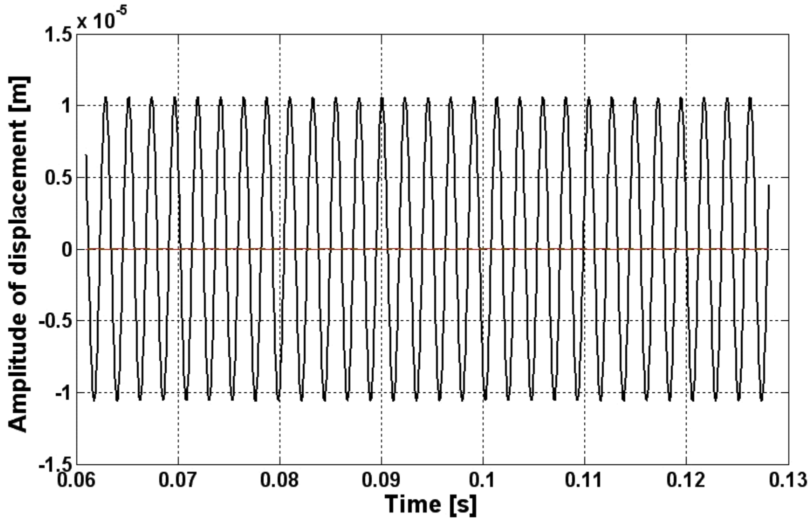

Fig. 2. Amplitude of displacement for the model of the present assembling technology

Fig. 3. presents the amplitude of displacement obtained as a result of numerical simulations for the second calculation model where the rails were founded on a thin layer of EPY resin. Similarly to fig. 2, the amplitude of displacement for direction Y is dominant while the amplitude of dislocation for the other directions is relatively small. For this model, the value of the amplitude of displacement is about 2.5 µm.

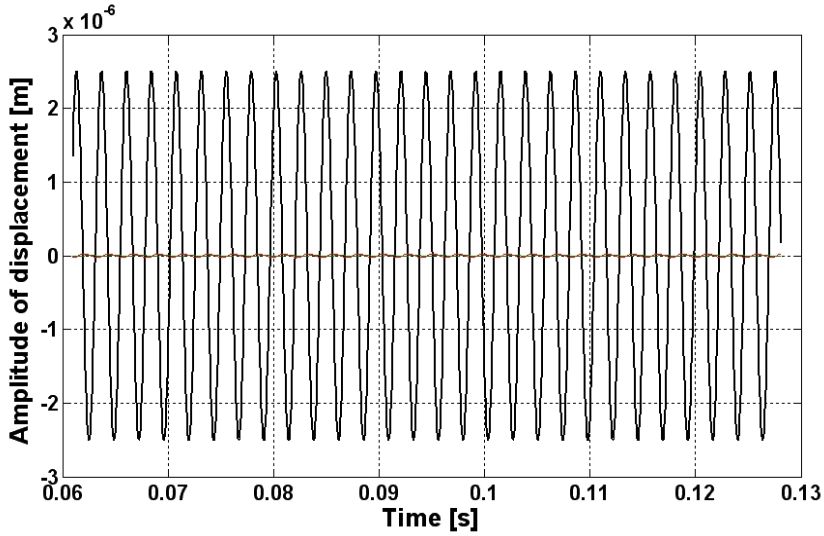

Fig. 3. Amplitude of displacement for the model of assembly on a thin layer of EPY resin

Numerical simulation on a simple model of the milling table indicated that the use of a thin layer of EPY resin positively influences the reduction in the relative vibrations between the tool and the workpiece. The use of a thin layer of EPY resin for the assembly of guide rails made it possible to reduce the amplitude of vibrations by about 77%.

3. EXPERIMENTAL STAND

The reduction in the amplitude of vibrations obtained as a result of numerical simulations of the milling table model with its guideway system founded on a thin layer of EPY resin induced the authors to perform an experimental verification of the obtained results. The test stand used for that purpose, presented in Fig. 4, is similar to the model used during the simulation.

The stand consisted of a body element with a table founded on top with the use of a ball guideway system. The body was made of grey cast iron. The mass of the body element was 314 kg. The guideway connection was made with the use of ball guideway elements consisting of two guide rails of size 25 and 1410 mm length, on which four guide carriages were moving (two carriages per each rail). A table, also made of grey cast iron, with the mass of 69.4 kg was founded on the carriages. The guideway elements were founded with the use of side fixing slits in accordance to the recommendations of the guideway system producer. The screw connections of the guideway system were tightened up with a torque recommended by the producer. In addition, a turned lead-screw with the external diameter of 24mm and the lead of 6mm was used to position the table.

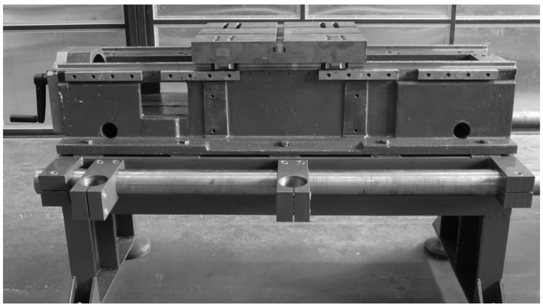

Fig. 4. View of the stand for experimental tests of the milling table

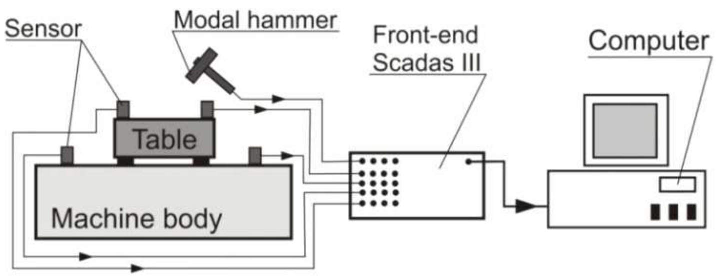

Fig. 5. Scheme of the test stand used for dynamics investigation

Front-end Scadas III was used during the dynamics experimental investigation for measurement points used in the dynamics experimental investigation acquiring the measurement signals. The excitation was done by means of a Kistler modal hammer. Kistler and PCB sensors were used for measuring acceleration. The measurement data was processed with the use of LMS Test Lab software. Fig. 5 presents a scheme of the stand used for dynamics experimental investigation. 33 measurement points were located on the tested object including: 8 points on the guide rails, 8 points on each body element, 4 points on guide carriages (one on each carriage) and 13 measurement points on the table. Fig. 6 presents geometry of the stand.

During the experimental investigation, the tested system was excited successively in two points. One of the excitation points was located in the central point of the table and the direction of excitation for this point corresponded to Z. The second excitation point was located on the side surface of the table near the guide carriage. In this case the direction of excitation corresponded to +Y. The directions of excitation are presented as arrows in Fig. 6. Frequency response function (FRF) was determined for each of the tested directions based on 30 realizations of the excitation signal.

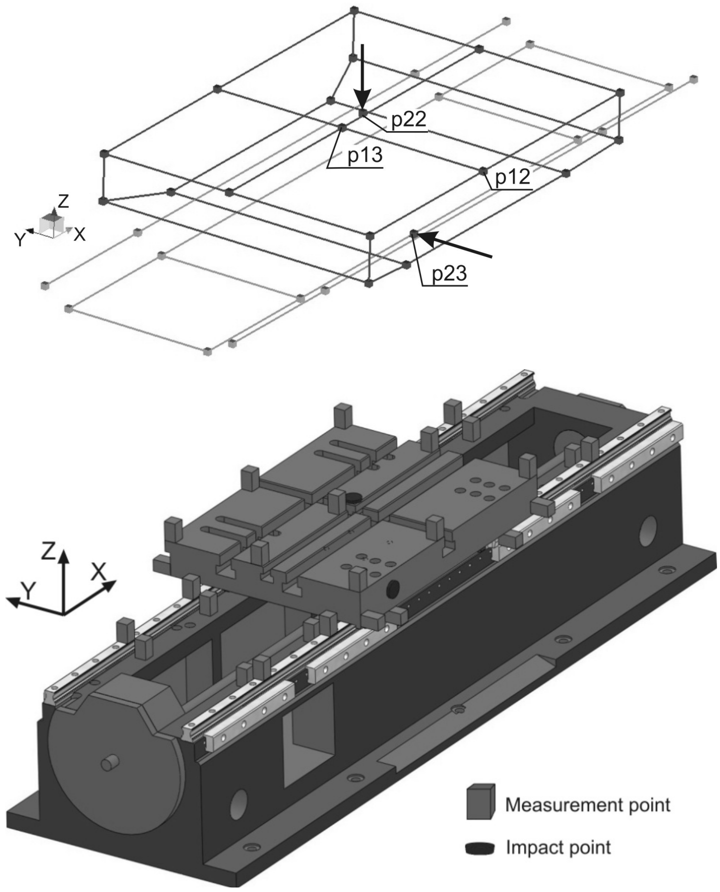

Fig. 6. Geometry of the measurement points in the dynamics experimental investigation

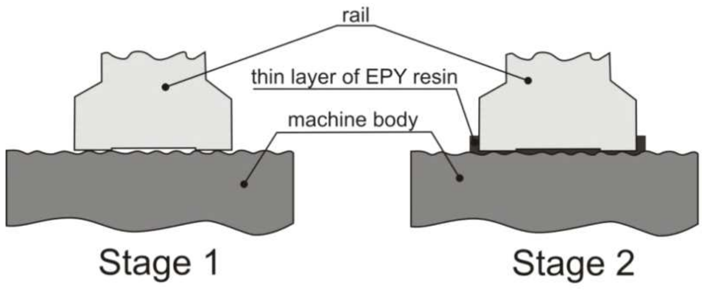

Fig. 7. Schema of investigation stages

The experimental investigation was conducted in two stages (Fig. 7). In the first stage, the test stand was assembled in accordance with the assembling technology recommended by the producer of the guideway elements. Between the guide rail and the body element there was a steel-steel contact. The assembling surface of the bed was milled precisely. In the second stage, the guideway system was disassembled and a thin layer of the EPY resin was inserted between the guide rail and the body element.

4. RESULTS OF DYNAMIC TESTS

The modal test conducted during the experimental investigation makes it possible to compare the dynamics of the tested system. Frequency response functions were chosen in order to evaluate the proposed solution. Measurement point 13 was chosen for the excitation located in the central part of the table (22) while measurement point 12 was chosen for the point located in the area of the guide carriage(23) (Fig. 6).

Fig. 8 shows comparison of two frequency response functions (object without and with EPY resin) measured approximately in the center of the Table in Z direction (response measured at point 13 with excitation at point 22 – Fig. 6). The dynamic characteristic in Z direction of the investigated object assembled without the use of EPY resin is dominated by 4 modes with resonance frequencies around 63 Hz, 330 Hz, 455 Hz and 495 Hz. The peak around 63 Hz is influenced by closely spaced two similar modes (Fig. 9): first one corresponds to the in-phase oscillations of the bed and the table whereas second mode corresponds to the similar motion and relative bed-table rigid body motion. Since these two modes are dominated by the object moving along Z direction on isolation pads (Fig. 9), application of EPY resin between the rails and the bed has insignificant impact on the magnitude of the FRF in the vicinity of the 63 Hz peak (Fig. 8). The other three modes, i.e. 330 Hz, 455Hz and 495 Hz (Fig. 10) are related mostly to the bending of the table. These modes exhibit also the relative table-bed motion and therefore a thin layer of EPY resin causes a decrease of the FRF magnitude within their vicinity. The FRF □ccurring in the vicinity of 495 Hz and 455 Hz modes decreased from 1.5 μm/N to 0.8 μm/N and from 1.1 μm/N to 0.4 μm/N respectively.

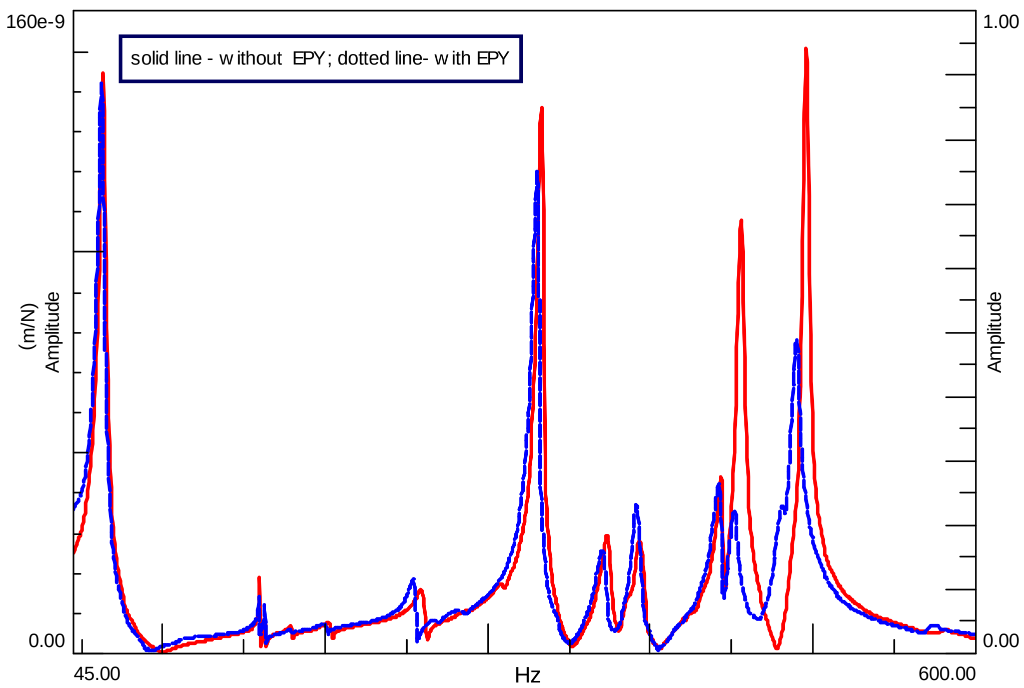

Fig. 8. FRF in point 13 with excitation in point 22 in direction –Z

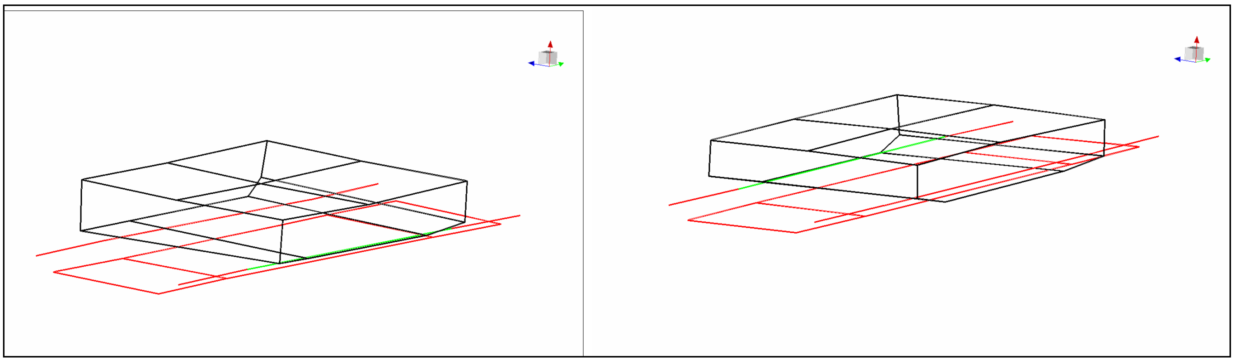

Fig. 9. Illustration of the modes □ccurring at 63Hz

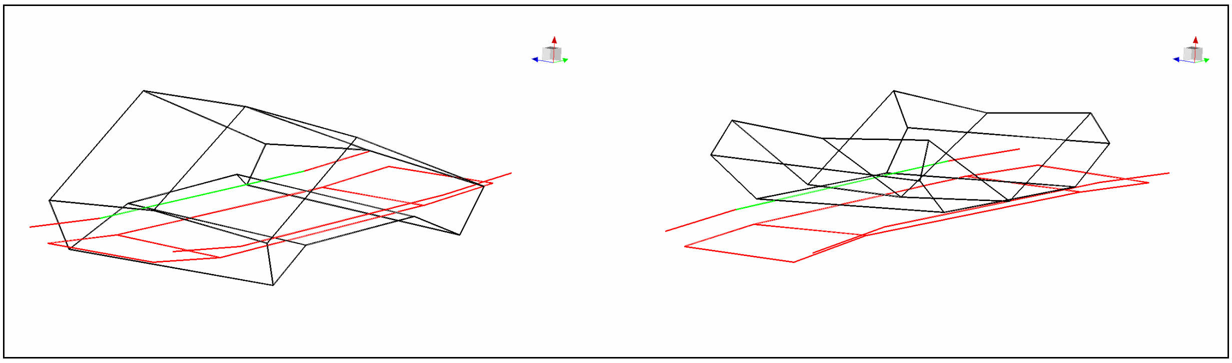

Fig. 10. Illustration of the mode □ccurring at 495 Hz

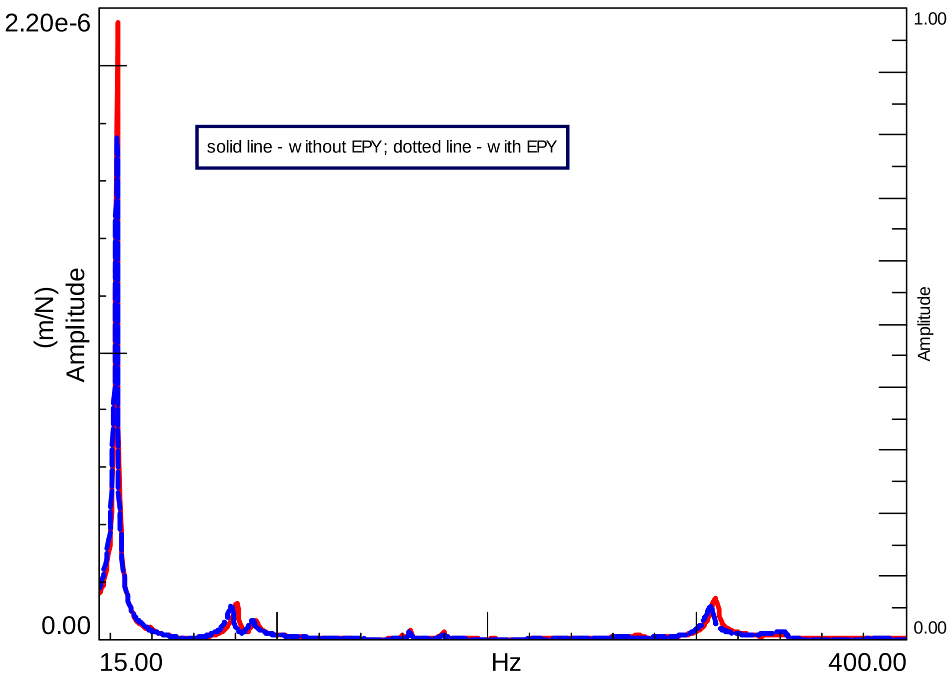

Fig. 11. FRF in point 12 with excitation in point 23 in direction +Y

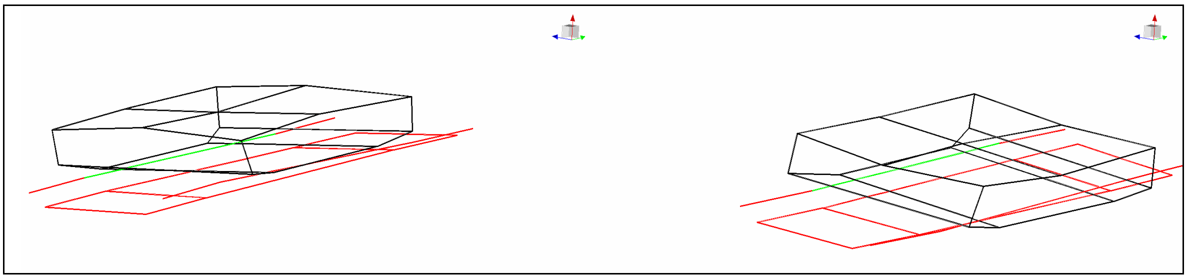

Fig. 12. Illustration of the mode □ccurring at 24 Hz

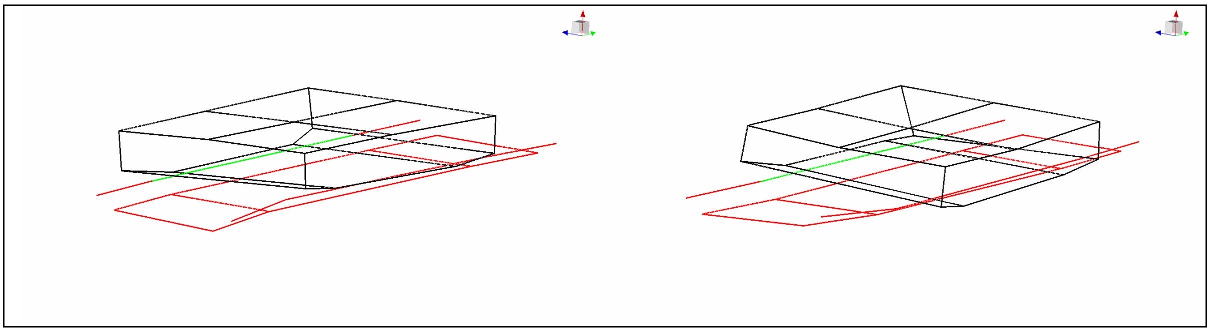

Fig. 13. Illustration of the mode □ccurring at 83 Hz

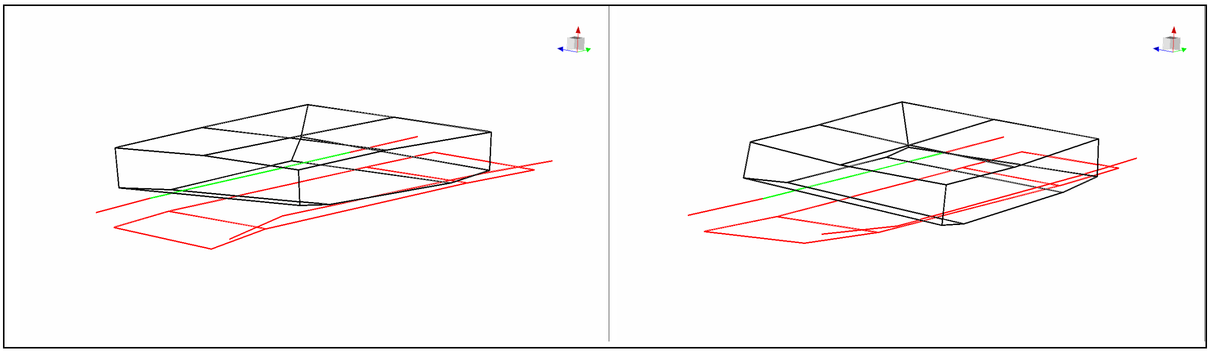

Fig. 14. Illustration of the mode □ccurring at 307 Hz

Figure 11 presents FRF in point 12 with excitation in point 23 (Fig. 6) along Y direction. Dynamic characteristics of the system in Y direction is dominated by the mode around 24 Hz where the bed and the table rotate around X axis (Fig. 6). This mode is characterized also by the relative bed-table motion (Fig. 12) which is attributed to the decrease of the amplitude from 2.1 μm/N to 1.7 μm/N. There are two other modes that influence FRF in Y direction: 83 Hz and 307 Hz modes. The 83 Hz mode corresponds mostly to the relative bed-table motion in Y direction (Fig. 13). At this frequency the FRF amplitude decreased from 0.13 μm/N (without EPY) to 0.11 μm/N (with EPY).

The 307 Hz mode where the table vibrates about Z axis (Fig. 14) was also slightly influenced by the application of the EPY resin. The FRF amplitude at this frequency was reduced from 0.14 μm/N to 0.115 μm/N.

5. CONCLUSIONS

Numerical simulation performed on a model of the milling table indicated that the use of a thin layer of the EPY resin may positively influences the reduction in the relative vibrations between the tool and the workpiece. The decrease in the level of vibrations has has a direct influence on the improvement of the machining precision. As a result of the performed simulation a decrease was obtained in the amplitude of vibrations by about 77% for the new assembling method of guide rails with the use of a thin layer of EPY resin.

The conducted dynamics investigation confirms the results obtained from numerical analyses. The conducted impulse tests indicated that the use of a thin layer of EPY resin may positively influences the improvement of stiffness-dissipation properties of the object. An increase in the dynamic stiffness of the system was obtained for two tested perpendicular directions Z and Y. An increase in the dynamic stiffness resulting from increased damping in the layer of EPY resin occurred in the areas of dominant modes, where bed and table relative motion was observed.

Application of the EPY resin does not reduce significantly the overall static stiffnees of the guideway system. According to the static tests performed on a short (300 mm) sample of the guide rail the static stiffness reduced from about 16 000 N/ μm to 11 700 N/μm. Although this might be considered as a significant reduction but the weak spot in the guideway system is carriage. Static stiffness of the carriage for the considered system was about 1000 N/μm. Since these two elements (guide rail-bed and carriage) might be modeled as two serial springs the resultant stiffness decreases from 941 N/μm to 921 N/μm.

The presented proposal for the assembly of the guideway system with the use of a layer of EPY resin might be very attractive from the practical point of view. The attractiveness of the proposed solution results from reduction in the preparation costs of the assembly surfaces for the guide rails as well as from its simple use.

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