DYNAMICS OF GUIDEWAY SYSTEM FOUNDED ON CASTING RESIN

Bartosz Powałka, Tomasz Okulik

Summary

The work presents simulation research on a milling table model founded with the use of a ball rail system. The simulation research confronted the present technology for assembling the guideway system with a new solution making use of a thin layer of a casting resin for assembling the guideway system. The results obtained during the simulation indicated that the use of a resin has a positive influence on the dynamics of the system. Additionally, in order to verify the results obtained analytically, dynamics experimental investigation was conducted for a guideway combination consisting of a body and a milling table. The dynamics was compared with the use of a frequency transition function in an impulse test.

Keywords: EPY resin, dynamics investigation, ball rail system, guideway

Właściwości dynamiczne układu prowadnicowego posadowionego na warstwie tworzywa EPY

Streszczenie

W pracy przedstawiono wyniki badań symulacyjnych modelu stołu frezarki posadowionego z użyciem tocznych prowadnic szynowych. Porównano dotychczasową technologię montażu układu prowadnicowego z nowym rozwiązaniem. Zastosowano cienką warstwę tworzywa EPY do montażu układu prowadnicowego. Uzyskane wyniki symulacji wykazały, że wprowadzenie tworzywa EPY poprawia właściwości dynamiczne układu. Weryfikacji tych wyników analitycznych dokonano w dynamicznych badaniach doświadczalnych połączenia prowadnicowego składającego się z korpusu oraz stolika obrabiarki. Właściwości dynamiczne porównano przy użyciu częstotliwościowej funkcji przejścia określonej w próbie impulsowej.

Słowa kluczowe: tworzywo EPY, badania dynamiczne, toczne szyny prowadnicowe, prowadnice

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, 2], which contributed to deterioration in the accuracy of the machine tool positioning. The

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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 [3, 4] or using a mixture of aggregate, sand and resins [5].

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 [6]. The second development direction involves improving the stiffness properties [7]. The third direction involves increasing the dissipation properties, which is done by using pads of polymers for the construction of the guide carriage [8].

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 [9] 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 [10]. 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 in chapter six. The experimental research makes use of the modal test.

2. Construction of 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]. Figure 1 presents the 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.

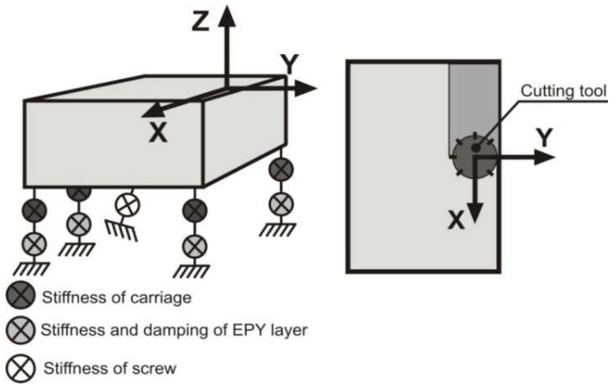

Fig. 1. Schema of the milling table simulation model

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 tool rotational speed in the resonance area for direction Y was 3225 RPM. 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 in the resonance area for direction Y was RPM.

3. Simulation results

The workpiece machining precision is influenced by the relative displacements between the workpiece and the tool in the tool working point. Figure 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 ca. 11 µm.

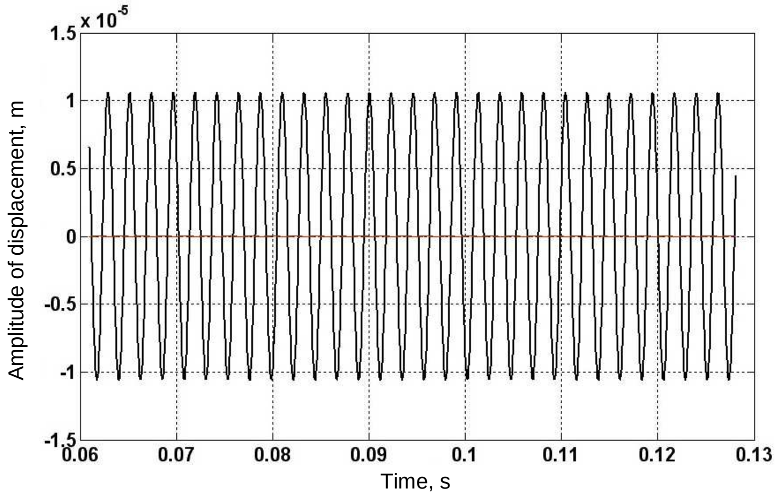

Fig. 2. Amplitude of displacement for the model of the present assembling technology

Figure 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 ca. 2.5 µm.

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 ca. 77%.

4. Stand for dynamic experimental tests

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.

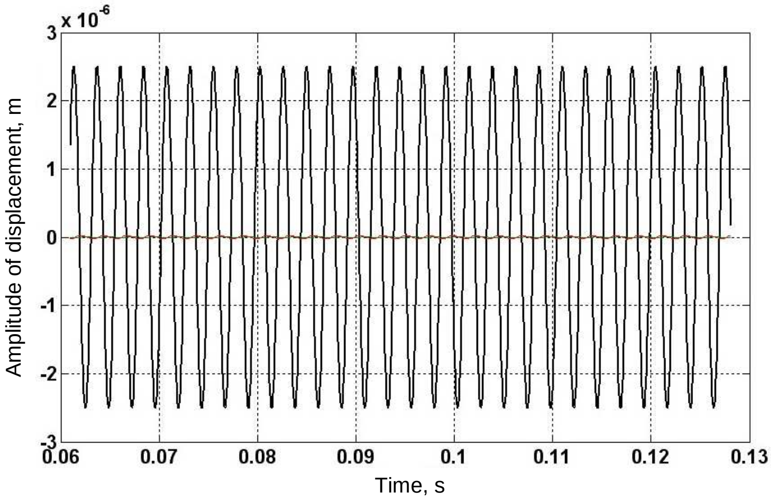

Fig. 3. Amplitude of displacement for the model of assembly on a thin layer of EPY resin

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 ca. 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 24 mm and the lead of 6mm was used to position the table.

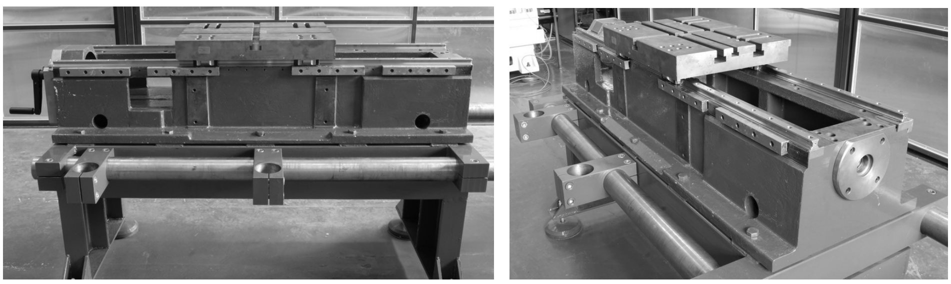

Fig. 4. View of the stand for experimental tests of the milling table

5. Dynamics experimental investigation

Front-end Scadas III was used during the dynamics experimental investigation for 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. Figure 5 presents a scheme of the stand used for dynamics experimental investigation. Thirty three 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. Figure 6 presents geometry of the measurement points used in the dynamics experimental investigation.

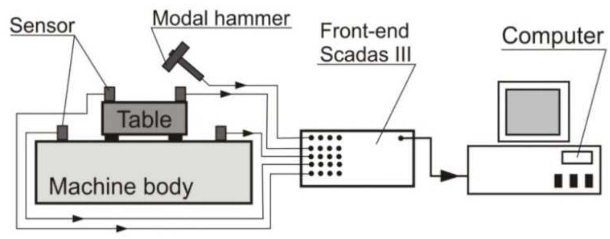

Fig. 5. Scheme of the test stand used for dynamics investigation

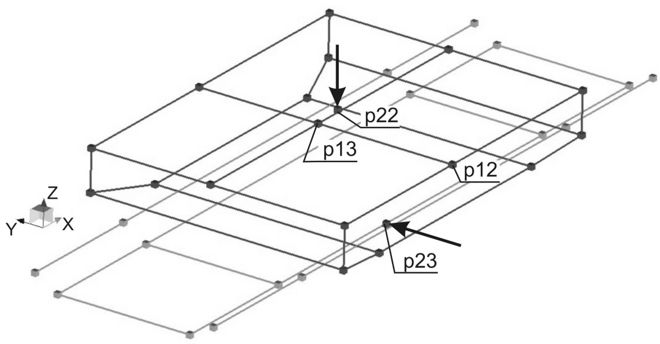

Fig. 6. Geometry of the measurement points in the dynamics experimental investigation

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 Figure 6. Frequency response function (FRF) was determined for each of the tested directions based on 30 realizations of the excitation signal.

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. During the assembly the surplus of the resin was squeezed out and EPY resin only filled the irregularities on the contact surfaces of the guideway system. Fig. 8 presents a fragment of the guideway connection of the test stand with a thin layer of EPY resin used during the second stage of the experimental investigation.

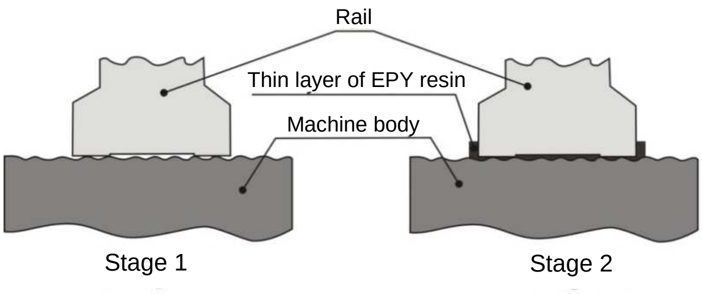

Fig. 7. Schema of investigation stages

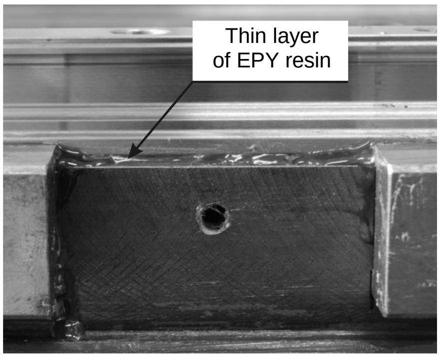

Fig. 8. Fragment of the guideway connection with a thin layer of EPY resin – the second stage of the experimental investigation

6. Results of the dynamics experimental investigation

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).

Figure 9 represents comparison of two frequency response functions in point 13 with excitation in direction –Z. The registered characteristics are very similar for the frequency of about 450 Hz. The use of EPY resin above the frequency of 450 Hz caused a decrease in the resonance frequency for two dominant resonances from 456.3 to 451.7 Hz and from 496.2 to 490.1 Hz (most probably caused by a slight decrease in stiffness resulting from the use of EPY resin). The amplitude for the dominant resonances decreased quite considerably from 0.090 to 0.029 g/N for the resonance of 456.3 Hz. This is a reduction in the amplitude by 67.8%. For the resonance of 496.2 Hz the amplitude decreased from 0.149 to 0.075 g/N. In this case the amplitude decreased by 49.7%. The amplitude decrease was caused by an increase in damping through the use of EPY resin.

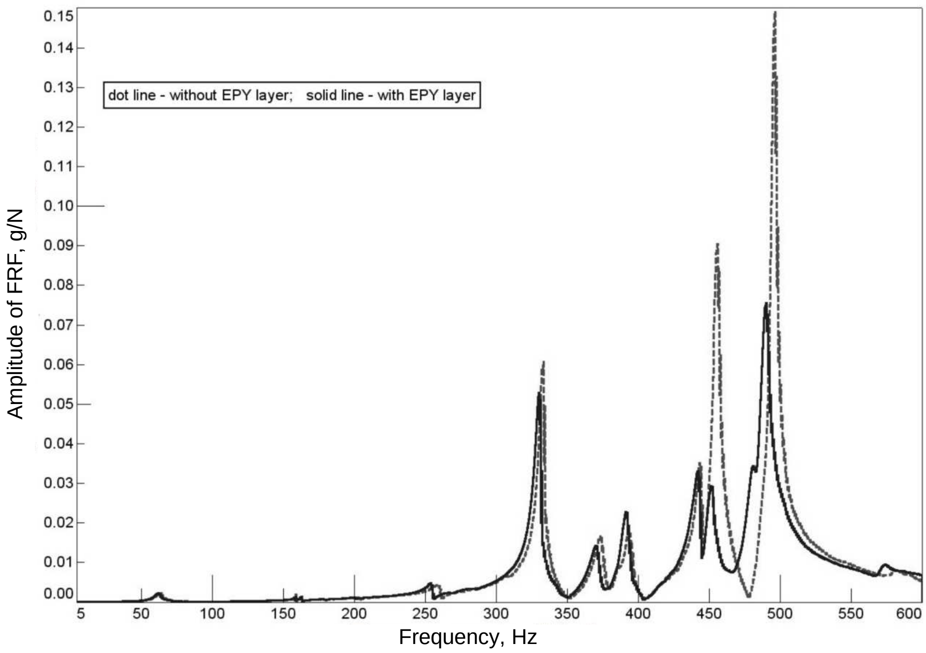

Fig. 9. FRF in point 13 with excitation in point 22 in direction -Z

Figure 10 represents comparison of two frequency response functions in point 12 with excitation in direction +Y. In this case, the dominant resonance is located near 300 Hz. Characteristics for the frequency range from 5 to 280 Hz and for the range from 350 to 600 Hz are very similar. The resonance with the frequency of 309.1 Hz is dominant in this direction. An amplitude decrease occurred in the resonance from the value of 0.055 g/N in case of the present assembling technology to the level of 0.044 g/N for the assembly of guide rails with the use of a thin layer of the EPY resin, which is a decrease by ca. 20%.

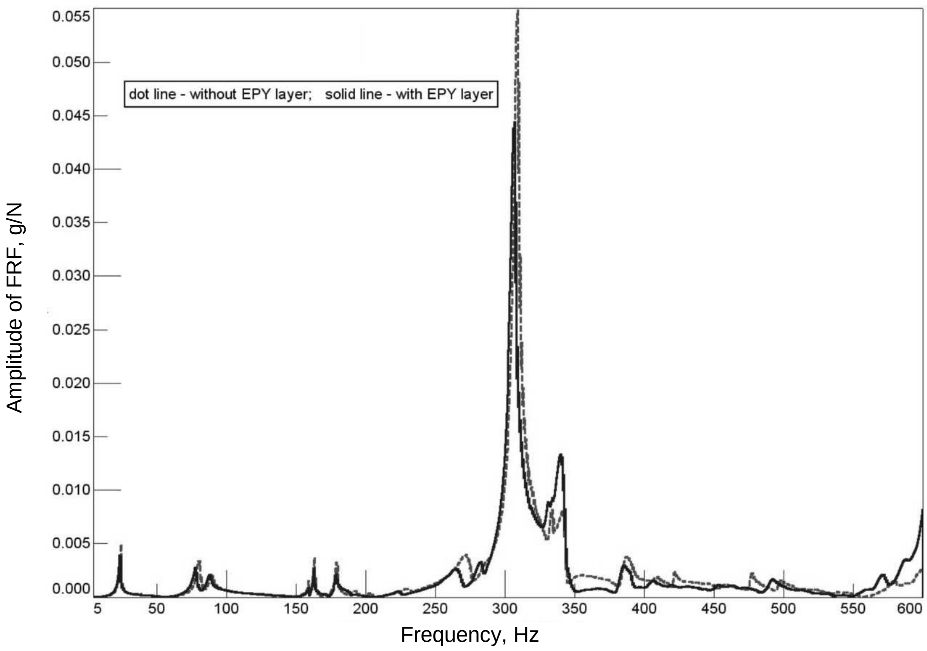

Fig. 10. FRF in point 12 with excitation in point 23 in direction +Y

7. Conclusions

Numerical simulation performed on a model of the milling table indicated that the use of a thin layer of the EPY resin positively influences the reduction in the relative vibrations between the tool and the workpiece. The decrease in the level of vibrations has 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 ca. 77% for the new assembling method of guide rails with the use of a thin layer of EPY resin.

The conducted dynamics investigation completely confirms the results obtained from numerical analyses. The conducted impulse tests indicated that the use of a thin layer of EPY resin 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 resonances, which are responsible for the dynamics of the system.

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.

The solution presented in the work is the subject of patent application no P388153 in the Patent Office of the Republic of Poland.

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