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NUMERICAL MODEL OF FRICIONAL DAMPER FOR GLAS-MAKING ROBOT LANCE

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Abstract

The need to design a friction damper for glass-making robots arose because of the excessive vibrations, which occur in the course of their work. The robots are commonly used in the manufacture of glassware. The vibrations adversely affect the work of ball gatherers, which results in a large number of defects in the finished glass products. As a result of the vibrations molten glass may become unevenly distributed on the ball's surface and as the material flows down the ball into the mould the thermal conditions of its solidification may change. It is proposed to damp the vibrations by means of a prototype friction damper mounted directly on the ball gatherer lance. The glass-making robot lance with the friction damper was modelled. The vibrations of the glass-making robot lance tip under static load and impact excitation were measured during simulations. Also the relative displacements of the damper rings in the course of the excitations were measured. Moreover, the dependence between the preload force and the system's damping decrement was determined. The main aim was to select proper operating parameters for the proposed structure in order to obtain maximum system damping.

Keywords: *robot, vibration damping, friction damper, numerical model, damping decrement*

1. Introduction

The main function of glass-making robots, also referred to as ball gatherers, is to transfer molten glass from the furnace to the moulding device. The robot's executing element, which directly transfers molten glass, is a lance tipped with a ball. Before glass-making robots were introduced into glassworks, their work had been done by people. However, the working conditions during the production of glassware had been hard for the workers. The high temperature of the glass furnace, the high noise level, and the monotony of the performed operations contributed to considerable defectiveness and deterioration in the quality of the finished product. The use of glass-making robots in the manufacture of glassware brings certain benefits, such as the delivery of the precise amount of molten glass in a short time, more uniform molten glass, no air bubbles in the glass and higher quality of the products.

The manufacturing process involving robots to produce glassware is similar to the one in which glassware is manually moulded (Fig. 1). In the initial stage of this process, the robot puts the ball rotating around the lance axis into the furnace with molten glass. Molten glass is gathered on the ball's surface. After it leaves the furnace the rotating ball is brought to a position above the moulding device and once the ball stops rotating the molten glass spontaneously drips (as a result of gravity) into the mould. Between the dripping portion of molten glass and the ball, there remains a thin stream of molten glass, which is mechanically cut off with scissors. In the final stage of the manufacturing, process the gatherer ball returns to the furnace. During its return, the rotary motion around the lance axis is turned on again and the manufacturing cycle is repeated.

In the course of the manufacturing process, the operation of the ball gatherer may be disturbed by excessive vibrations, which adversely affect the quality of the manufactured products. Such vibrations result in the uneven distribution of molten glass on the ball's surface and when they occur while the material drops from the ball into the mould, they change the thermal conditions of its solidification. This results in various flaws on the surface of the products and so in the deterioration of their aesthetic appearance.

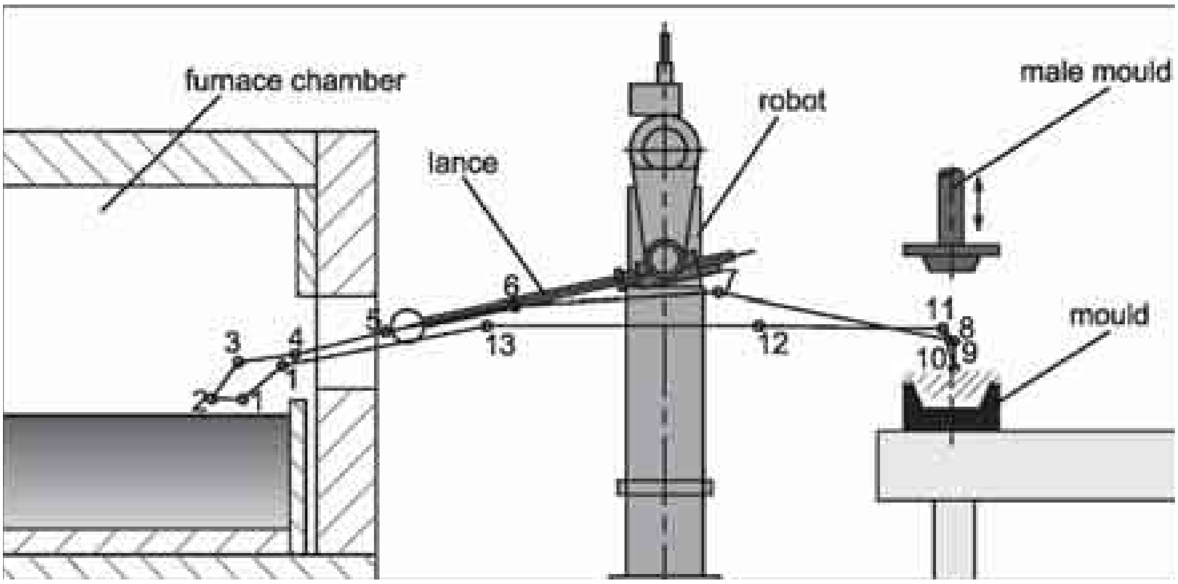

Fig. 1. Trajectory of gatherer ball motion: 1-4 molten glass is gathered from furnace, 4-8 glass is transported from furnace to moulding device, 8-10 motion of ball over moulding device, 10-14 ball returns to tank furnace [1, 2]

Studies carried out in the Institute of Production Engineering and Automation at Wroclaw University of Technology [3, 4] showed that the vibrations, which most adversely affect the manufacturing process, are the ones generated by the excitations caused by the forces of inertia of the robot's executing members as they are being accelerated, braked, or reversed. Laboratory and industrial tests of the robot's load-bearing structure showed that in the vibration spectrum there is one dominant relatively low natural frequency connected with a local vibrating system, which is the lance with the ball. The high compliance of the lance stems from its design. In the lance, there is an axial hole for transporting the cooling medium. Moreover, the lance has a long outreach needed to gather molten glass from the furnace.

An analysis of the robot work cycle shows that the strongest vibrations occur during the gathering of molten glass by the ball and delivering it to the mould. During the gathering of molten glass from the furnace, the vibrations are quickly damped owing to the consistence of the molten glass, but they may result in the uneven distribution of the latter on the ball's surface. During the delivery of the molten glass to the moulding device, vibrations are generated by the inertial forces produced by the stopping of the lance above the mould. The vibrations result in the uneven filling of the mould and the appearance of flow lines on the surface of the moulded glassware.

There are several ways in which the amplitude of the vibrations of the executing element can be reduced. One is to increase the stiffness of the lance by reducing the size of the cooling hole or to increase the cross section of the lance. However, if the cross section were increased this would result in greater weight of the executing element while the basic free vibration frequency would not change as a result. Moreover, this solution involves interference into the structural design of the ball gatherer. Another way of reducing the amplitude of lance vibrations is to change the robot control. This can be done by reducing the speeds and accelerations of the individual members of the robot. In addition, smooth braking of the ball over the moulding device and smooth starting of the ball in the place where molten glass is gathered can be introduced. However, this depends on the capabilities of the control system. Each of the above solutions would involve interference into the design of the robot or its control system (replacement of the controller and the drives). The last way of reducing the amplitude of ball gatherer vibrations is to use a frictional damper mounted directly on the glass-making robot's lance. The latter solution is presented in this paper.

2. Description of damper model

Today frictional dampers, and also inertial dampers, are installed in the places where the largest displacement amplitudes occur. In the case of glass-making robots, the largest amplitudes occur at the end of the executing element, i.e. on the gatherer ball. Because of the manufacturing process constrains a frictional damper cannot be attached there. In a new idea of lance vibration damping, a frictional damper is mounted in the place where the largest stresses occur. In the case of the considered glass-making robot, the largest stresses occur in the place where the lance is fixed to the robot's arm, i.e. in the place most distant from heat sources.

The principle of operation of the proposed frictional damper consists in the exploitation of the friction between the damper's spherical rings. Relative displacements of the rings result from the difference between the angles of rotation of the lance cross section in the places where the frictional rings are fixed. Considering the behaviour of the rings one can expect structural friction to occur on the friction faces. However, without carrying out laboratory tests one cannot predict how large relative displacements will occur on the damper's spherical surfaces. Will they be on the macroscale or merely on the microscale (within the limits of the preliminary advance) [5]?

A prototype frictional damper is shown in Fig. 2.

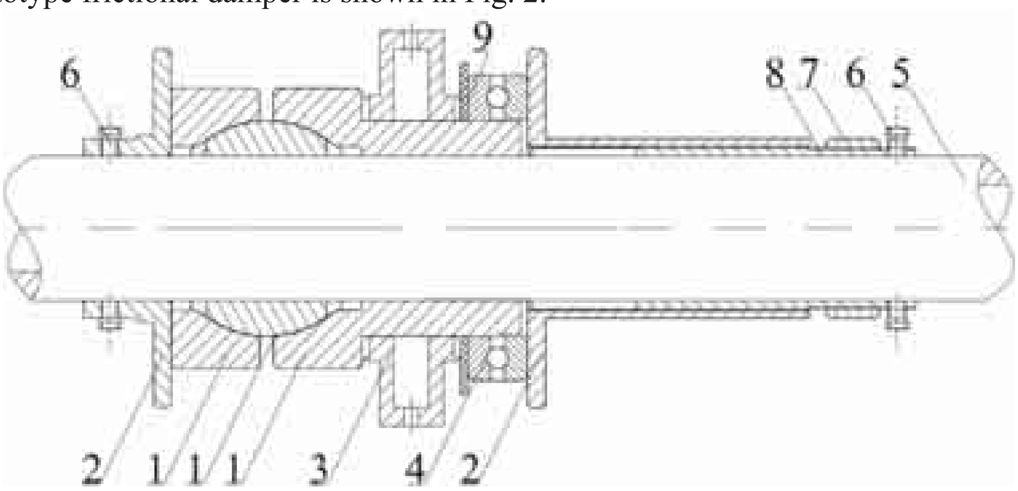

Fig. 2. Schematic of frictional damper mounted on glass-making robot's lance: 1 – damper's spherical frictional rings, 2 – preload rings, 3 – force gauge, 4 – thrust ball bearing, 5 – lance, 6 – rings locking bolts, 7 – nut, 8– preload bolt, 9 – flexible spacer

The frictional damper consists of frictional components in the form of three spherical rings (two external rings and one middle ring). The damper's frictional rings are pressed together by preloading rings and the preload force is applied via a bolt with a nut. The state of preloading was measured by means of a ring force gauge.

3. Numerical model

Before building a prototype laboratory model of the frictional damper, a numerical model of the latter was created. The robot's lance with the frictional damper mounted on it (Fig. 3) was modelled using the MSC ADAMS 2005 v.2 software [5]. A solid-type cast iron block (1) weighing 1127 kg was placed on insulating beams. The glass-making robot lance (2) was attached to the block. The lance was joined to the block via a fix kinematic pair whereby these elements were deprived of the ability to move relative to each other. The lance was modelled using compliant elements so that it could deform under gravitation and impact load. The ball free falling on an equivalent mass (4) would generate impact excitation. The lance mesh was built from Tetra elements using the AUTOFLEX module. Since the contact between two compliant elements of the flex type cannot be implemented in Adams 2005, the particular damper rings had to be modelled using stiff elements of the solid type, which represents a simplification of the model. The damper rings (3) were joined to the lance via additional markers fixed to the lance axis and via kinematic pairs. The joint between the left outer ring and the lance was modelled by a kinematic pair of the fix type and the joint between the middle ring and the right outer ring by translational kinematic pairs. To the last, spherical ring a force was applied along the lance axis in order to provide preloading between the frictional rings of the damper.

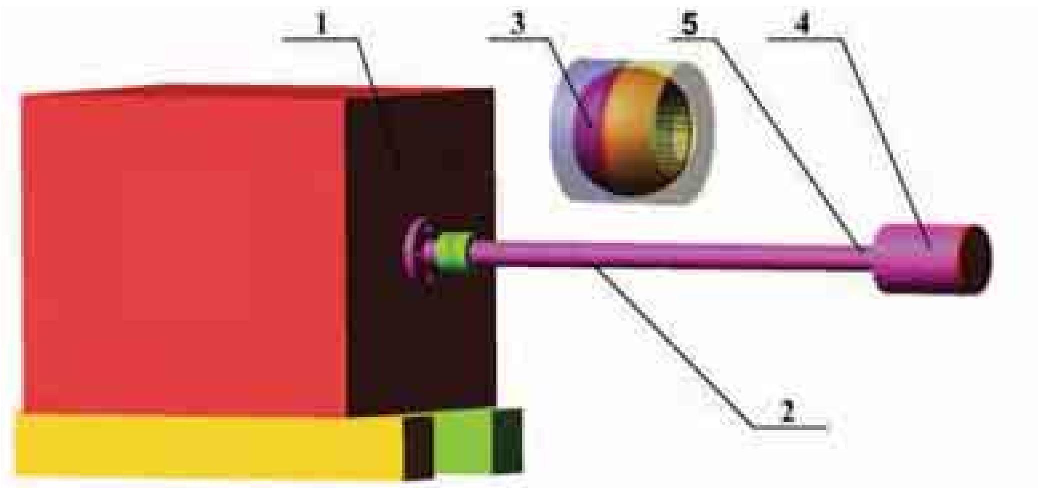

Fig. 3. Numerical model of glass-making robot's lance with frictional damper: 1 – cast iron block, 2 – lance, 3 – frictional damper, 4 – equivalent mass, 5 – lance end

4. Simulation results

During the simulation the static deflection of the lance and its vibrations in the vertical plane, related to a point on the equivalent mass, were determined. Fig. 4 shows the pattern of displacement of lance end vibrations after impact excitation. These are the vibrations of the system without and with the modelled frictional damper, respectively. The averaged damping decrement for the model without the frictional damper amounts to 0.055 while for the model with the frictional damper it amounts to as much as 0.23.

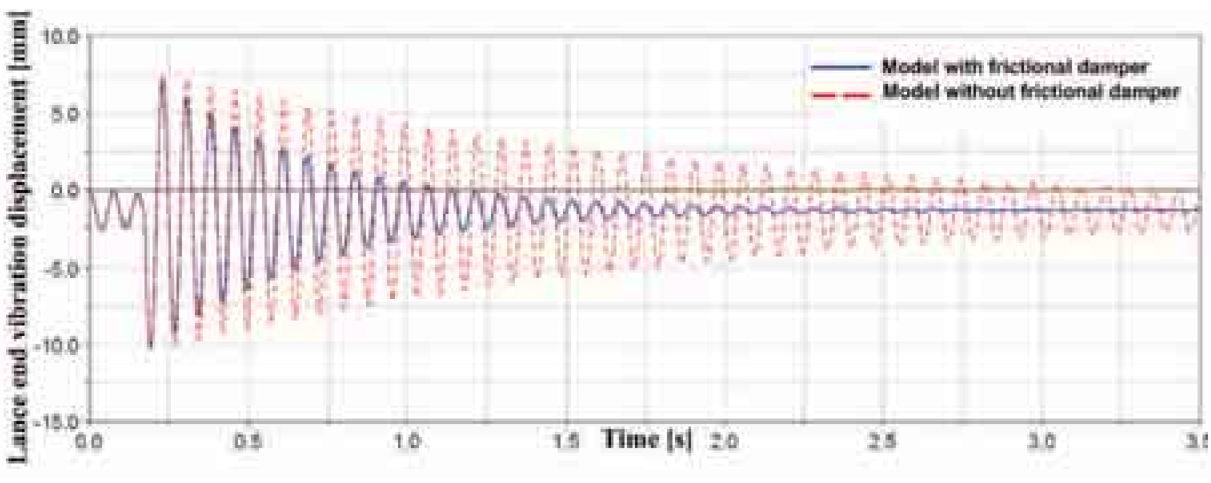

Fig. 4. Pattern of displacement of lance end vibrations after impact excitation, for model without and with frictional damper, respectively

In addition, the relative displacements between the damper's rings (Fig. 5) were determined. Markers were placed on the frictional rings and connected with respectively the inner ring (points 1, 3), the left outer ring (2) and the right outer ring (4). The points applied to the damper rings were located on the spherical surface of the caps of the spherical elements. The geometry of the damper spherical rings was modelled in such a way as to ensure surface contact between them. Due to the inaccurate representation (at the beginning of the simulation) of the ring cap geometry by the MSC Adams software the rings would merge. In order to prevent this, the individual spherical rings of the damper were moved apart by about 0.4 mm. Hence, in the diagram below the relative displacements start from 0.3925. In the course of the simulation, it was observed that first the surfaces of the rings would fit against each other. Then relative displacements between the measuring points of the inner ring relative to the outer ring, caused by the vibrations of the lance, would occur. The displacements were in the order of 20 μm. One can suppose that structural friction will take place and macrodisplacements will occur on the friction faces at high amplitudes of the vibrations in the contact. At lower amplitudes, microslips may occur on these surfaces.

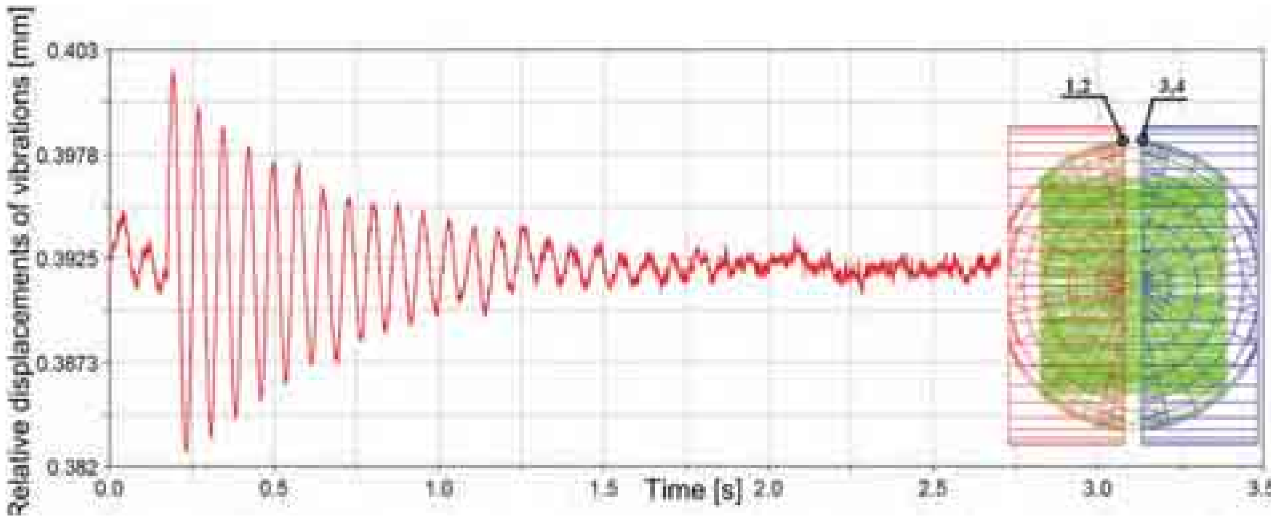

Fig. 5. Relative vibrations displacements of rings – 1, 3) points in which measuring markers were fixed to inner ring, 2,4) points in which measuring markers were fixed on left and right outer rings

In order to ensure preloading of the damper rings a force was applied along the lance to the last spherical ring and the dependence between damping decrement and the preloading force (Fig. 6) was determined. The damping decrement was determined from the damped vibration curve. In the numerical model an averaged damping, decrement was determined based on nine consecutive amplitudes. The diagram in Fig. 6 shows that damping decrement increases up to a certain value of the preloading force. The number of places in which the surface microirregularities of the caps of the frictional damper's spherical rings are in contact increases with the preloading force. As a result of the external load the contact surfaces of the frictional rings displace relative to each other. The work of the friction forces in the contact is determined by the number of places in which the slip of the surface microirregularities takes place and by the length of the slip paths. The friction is the sum of the elementary works of the friction forces on the respective paths of microslip between the uncoupled contact areas. When a certain value of the preloading force is exceeded, some of the places where surface irregularities are in contact become coupled together. As a result, the number of places where slip could occur decreases and so does the work of the friction forces. Therefore it is essential to select such a value of the frictional damper preloading force, which will ensure the best damping properties. If the preloading force is too weak the contact places may uncouple causing microslip in the contact. Whereas when the force is being increased, the number of coupled surface microirregularities in the contact increases whereby structural damping decreases. The numerical analyses showed that a distinct maximum in damping decrement occurs at the preloading force of 5000 N during the pressing of the rings. This is the optimum preloading force, which should be applied in order to obtain the best damping properties of the system.

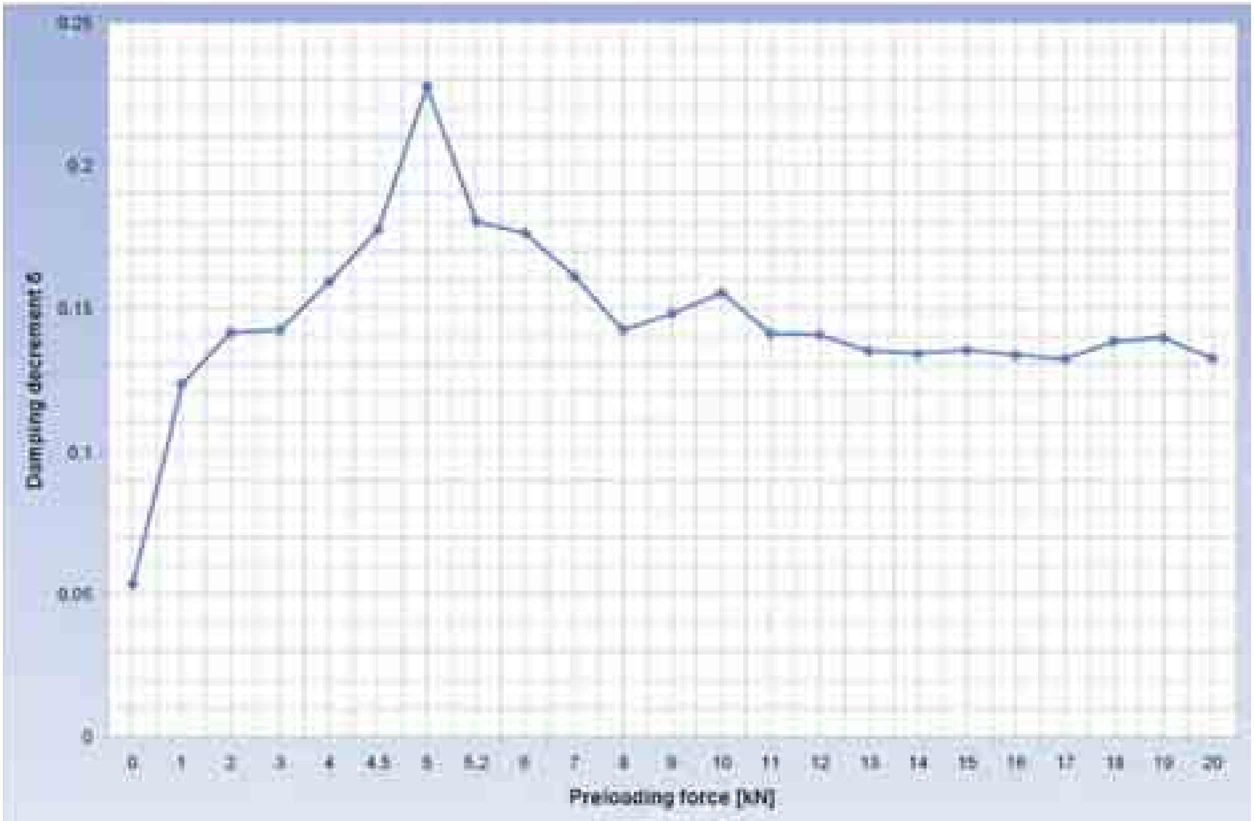

Fig. 6. Glass-making robot lance damping decrement versus damper rings preloading

The numerical model was partially validated by checking the fundamental eigenfrequencies of the numerical model lance and those of its physical model built on a laboratory test stand. The lance was modelled using the AUTOFLEX module (Fig. 7). A transition element (as it is in the real system) was introduced between the lance and the equivalent mass. The lance was fixed to the cast iron block via a flange connection. Depending on the amount of molten glass to be gathered, balls with different diameters, and so with a different weight, are used in ball gatherers.

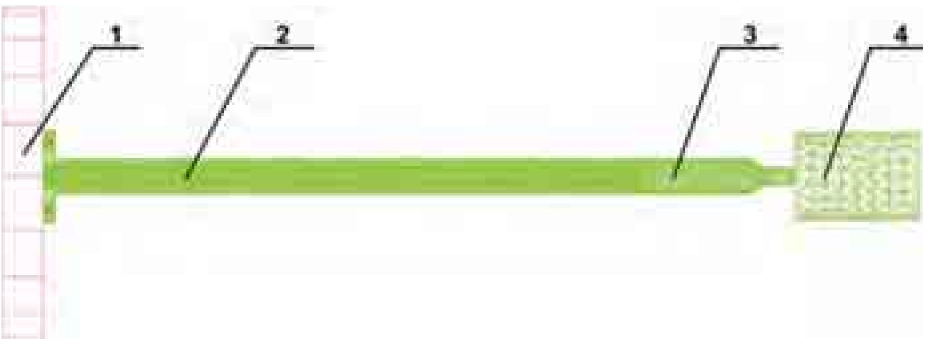

Fig. 7. Numerical model of lance without frictional damper: 1) stationary cast iron block, 2) lance, 3) transition element (end), 4) equivalent mass

Computations were performed for the lance alone and then the transition element and the next equivalent masses were added. The fundamental natural frequencies computed for the different combinations of equivalent masses are shown in Fig. 8.

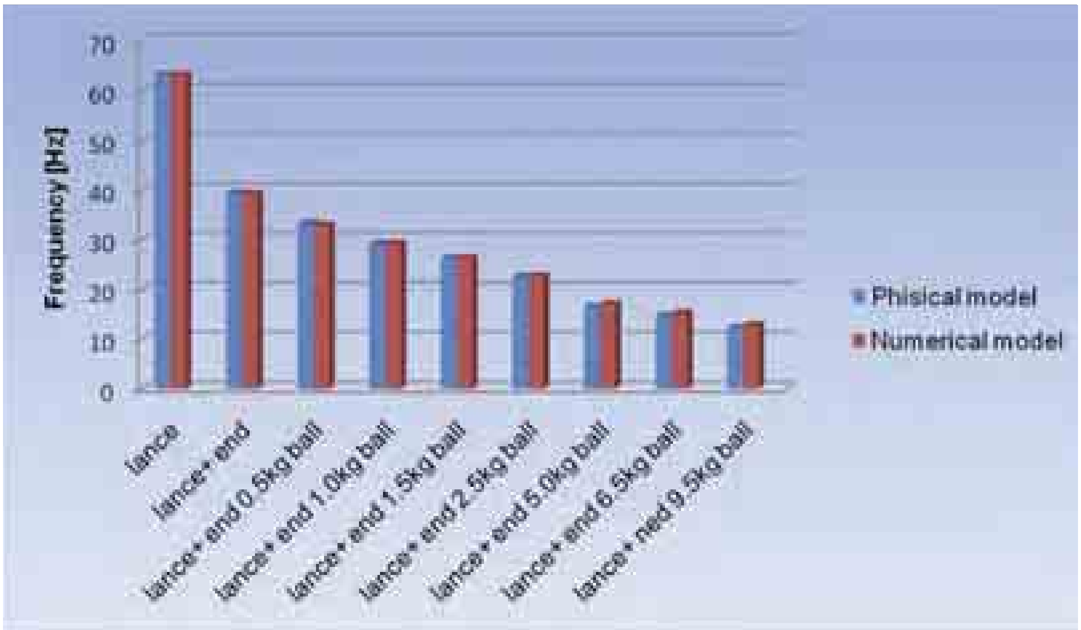

Fig. 8. Comparison of fundamental natural frequencies of lance numerical model and lance physical model for different equivalent masses

The results yielded by the numerical model and the physical model for the fundamental natural frequencies of the lance with the equivalent masses were found to be highly consistent. The larges discrepancies were found for the model of the lance with the transition element and an equivalent mass of 5.0 kg. The error amounted to 4%. The probable cause of the discrepancies is the inaccuracy in the measurement of the equivalent masses in the physical object.

5. Conclusion

The presented numerical model can be used to build a laboratory frictional damper and verify the results of further research into the damping of lance vibrations.
The present studies have shown that:

1) the numerical model is sensitive to a change in the inter-ring contact parameters (such as contact stiffness, penetration depth, static and dynamic friction coefficients),
2) the presence of the frictional damper results in an increase in the damping decrement for the glass-making robot executing element,
3) there exists an optimum preliminary clamping force at which the system is characterized by the best damping properties,
4) the preliminary validation of the numerical model by the physical model, consisting in the comparison of the fundamental eigenfrequencies, showed considerable agreement between the results yielded by the two models.

The model of the lance with the frictional damper will be fully validated on the basis of experimental results.

References

[1] Choroszt, T., Marek, B., Roszkowski, A., Skoczyński, W., Szymkowski, J., *Measurement of the vibrations of glass-making robots during the production cycle*, Przegląd Mechaniczny, Vol. LXIV, No. 9, pp. 196-199, 2005.

[2] Skoczyński, W., Roszkowski, A., Marek, B., *Efficiency of frictional and MR dampers in model of the robot lance,* Annals of DAAAM for 2008 & Proceedings of the 19th International DAAM Symposium, pp. 1269-1270, Slovakia 2008.

[3] Skoczyński, W., Krzyżanowski, J., Szymkowski, J., Poprawski, W., *Dynamic testing of ball gatherer prototype. Stage I: Laboratory tests,* The Institute of Production Engineering and Automation Report, Series: Reports, No. 20/02, Wroclaw 2002.
[4] Skoczyński, W., Choroszy, T., Krzyżanowski, J., Szymkowski, J., Poprawski, W., *The launch of the production of ball gatherers for the automation of molten glass delivery in glassworks. Stage II: Dynamic tests in industrial conditions (in Polish)*, The Institute of Production Engineering and Automation Report, Series: Reports, No. 28/02, Wrocław 2002.
[5] Lawrowski, Z., *Tribology, friction, wear and lubrication (in Polish),* Wrocław University of Technology Publishing House, Wroclaw 2009.
[6] *ADAMs User's Reference Manual*, MDI, Michigan, USA 2001.