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STEPS FOR A REDUCTION OF VIBRATIONS OF THE ROLLER GUIDE IN THE EINSTEIN-ELEVATOR

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Abstract

Future microgravity experiments in the Einstein-Elevator of the Hannover Institute of Technology (HITec), which is currently under construction, could be disturbed seriously by external vibrations [1]. To avoid possible vibrations caused by the gondola´s guide previously, the behavior of the guide components such as rollers and guide rail is simulated by a test. In a first step the life time of the rollers is estimated by a life time calculation before they are stressed with 25,000 test runs of the special Einstein-Elevator´s speed profile on an ad hoc developed test rig. After this test, the fitness of the rollers and of the guide rail is determined for use in the facility by examining the components and analyzing the vibrations occurred during the test runs using a frequency analysis to trace them back to their cause.

INTRODUCTION

In the future, the Einstein-Elevator of the Hannover Institute of Technology will allow innovative experiments in the areas of basic physical research and aerospace technology. Inside the large equipment, microgravity is created in a gondola for experiments for a short time. [2]

In order to conduct an experiment, a vacuum is created inside the gondola before it is sped up by linear motors from a standing position to over 20 m/s with quintuple gravitational acceleration. After that, the gondola performs a parabolic flight during which the experiments are weightless for about 4 seconds. [2]

The guides and especially the rollers used at the gondola for guiding purposes play an important role for the experiments [3],[4]. As the experiments can be strongly affected by external vibrations, these interfering influences are to be minimized as far as possible in order to ensure a high test quality. The danger of additional vibration caused by damages of the rollers through excessive stress or material fatigue over time also needs to be eliminated. Because of the extraordinary speed profile with its intense phases of acceleration and deceleration, the durability of the rollers must be tested with the help of a roller test rig. An estimation of the durability through a life time calculation of the relevant norms is not sufficient. After the completion of the test, possible damages as well as vibrations of the rollers are analyzed in order to find the cause for the occurring vibrations or to limit the increase of vibrations during the test. For this purpose, force and deviation measurements are conducted at the analyzed rollers in the roller test rig. The suitability of the rollers for the use in the Einstein-Elevator is finally evaluated through the analysis of the rolling elements' patterns and their running surfaces in the rollers as well as the contact areas between rollers and guide.

ROLLER TEST RIG

The roller test rig simulates the actual stress applied to the rollers in the Einstein-Elevator [5]. On this test rig the rollers roll on a drive disk, which corresponds to the guide rail in respect to surface texture. A test always analyzes two rollers at the same time. The setup of the roller test rig is presented in figure 1.

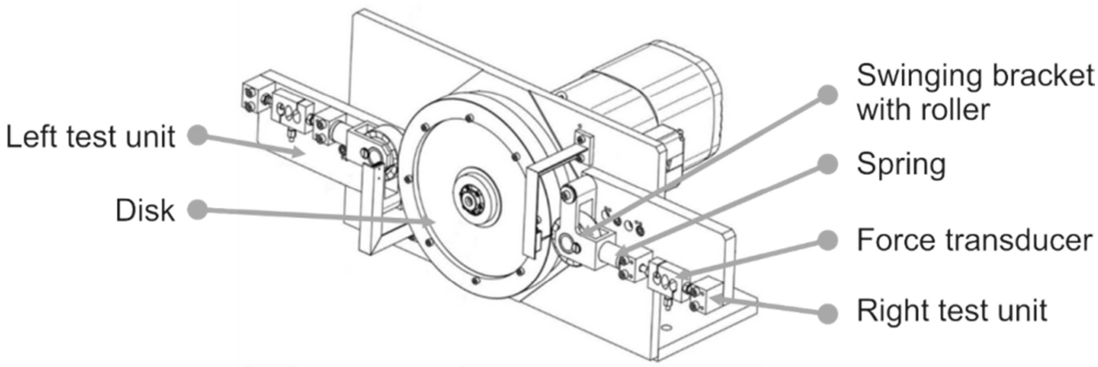

Figure 1: Roller test rig and test device [Source: ITA]

The test devices with the rollers (Ø 100 mm) are arranged opposite of each other to the right and left side of the drive disk. Every test device consists of a swinging bracket, a tension spring and a force transducer. The swinging brackets, which guide the rollers, are connected with the base plate through a plain bearing. With the help of the springs, the rollers are applied with a controllable minimum loading capacity and pressed on to the running surface of the drive disk. The force transducers' purpose is the measurement of the occurring forces during a test. The drive disk, which has a diameter of 400 mm, is powered by an electric motor and performs rotating movements, in order to strain the rollers and simulate the special speed profile of the Einstein-Elevator. Through this speed profile with its spontaneous but at the same time very intense phases of acceleration, the rollers are strained immensely.

ROLLERS

For the operation of the Einstein-Elevator, rollers of the type INA LR5308-2Z are being used. The rollers are designed as double row angular contact ball bearings and are therefore able to assimilate radial as well as axial forces at high rotational speed. In order to seal the bearings, shields made of sheet steel between the inner and outer ring are being used. Figure 2 depicts a corresponding roller.

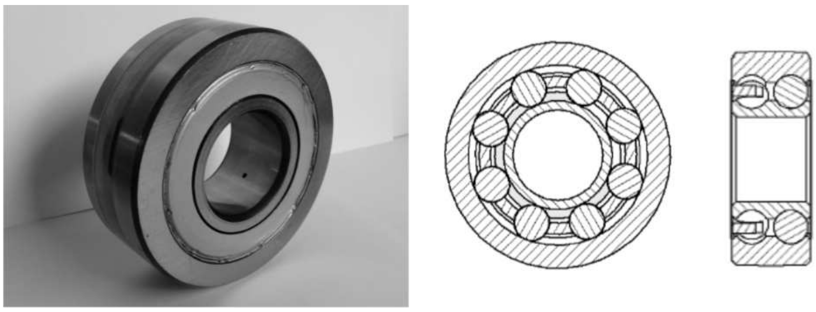

Figure 2: Roller LR5308-2Z [Source: ITA]

In order to eliminate the possibility of failure among the bearings during later operation, a life time calculation for the rollers is conducted first.

LIFE TIME CALCULATION

The rating life of the rollers is determined as defined in DIN ISO 281. A calculation of an extended durability is not necessary as the rollers will not be exposed to stress due to weather conditions, contamination or similar circumstances in the later operation. In order to determine the rating life $L_{10,}$ the dynamic load rating C_r and the equivalent dynamic bearing load P_r are put in perspective to each other. According to the manufacturer, C_r amounts to 54 kN for the used rollers, P_r follows from the preload force of 2 kN. Thus, the rating life can be determined by the following life time equation:

$$L_{10} = \left(\frac{C_r}{P_r}\right)^3 = \left(\frac{54\text{ kN}}{2\text{ kN}}\right)^3 = 19.683$$

As the life time is indicated in 10^6 revolutions, the result shows that under standard conditions 90 % of the used bearings perform a minimum of 19,683,000,000 rotations without showing damages caused by material fatigue. The rollers travel a distance of 52 m per test run, which corresponds to 172 revolutions if the rollers' perimeter is set at 0.314 m. Thus, the calculation results in the life time of 114,436,046 test runs in the Einstein-Elevator at an expected annual performance of ca. 25,000 runs. According to this calculation, a premature failure of a great number of used rollers is therefore not expected. However, during operation, the rollers are exposed to very intense accelerations which are not considered in the life time calculation. For this reason and despite the calculation of a sufficient durability, further tests at the roller test rig are aspired. There, the rollers are exposed to the annual performance in a continuous operation scenario in order to analyze them for damage afterwards.

REQUIREMENTS FOR THE TEST

The test aim is to prove that the rollers, which have been selected for the guide of the gondola inside the Einstein-Elevator, are suitable for this usage and that a sufficient durability can be expected. As every occurrence of vibrations reduces the quality of the future tests in the Einstein-Elevator, it also needs to be examined whether the rollers cause increasing vibrations due to material fatigue. With 250 days of operation and as far as 100 tests per day, the number of test runs amounts to 25,000 per year. This annual performance is to be simulated during the test phase. The temperature behavior of the rollers as well as the dimensional tolerances of the components at the roller test rig correspond to the subsequent conditions prevalent in the Einstein-Elevator.

TEST RESULTS

After the completion of the running test, the data and observations are evaluated and classified. Here, the vibration behavior, which was collected through the force values, is to be analyzed especially. For this purpose, the basic vibrational pattern is initially described before analyzing the mechanical marks on the rollers and drive disk.

Vibrational pattern during the test

During the test runs, vibrations are stimulated through the operation of the calibrated speed profile. Figure 3 initially shows the speed profile in perspective to the force progression during a test run.

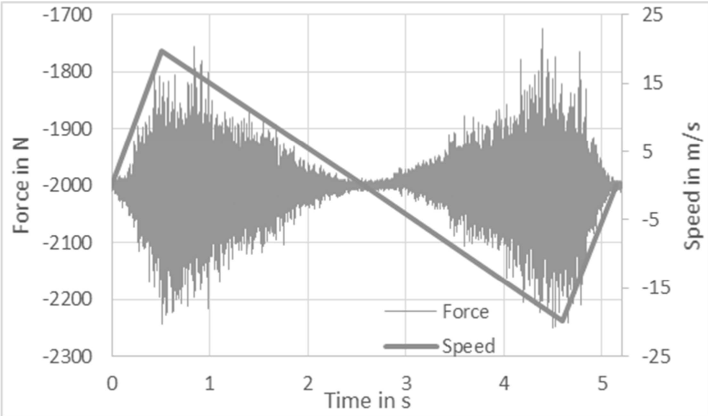

Figure 3: Vibrational pattern and speed profile of a test run

An increase of vibration during the phases of acceleration is clearly visible. Phases of slow speed reduce the vibrations. In the early phase of the test the vibrations are generally very weak. However, as the test progresses, the vibrations intensify significantly. Figure 4 shows vibrational patterns of a roller in different test phases. The preload force for every phase is ca. 2000 N.

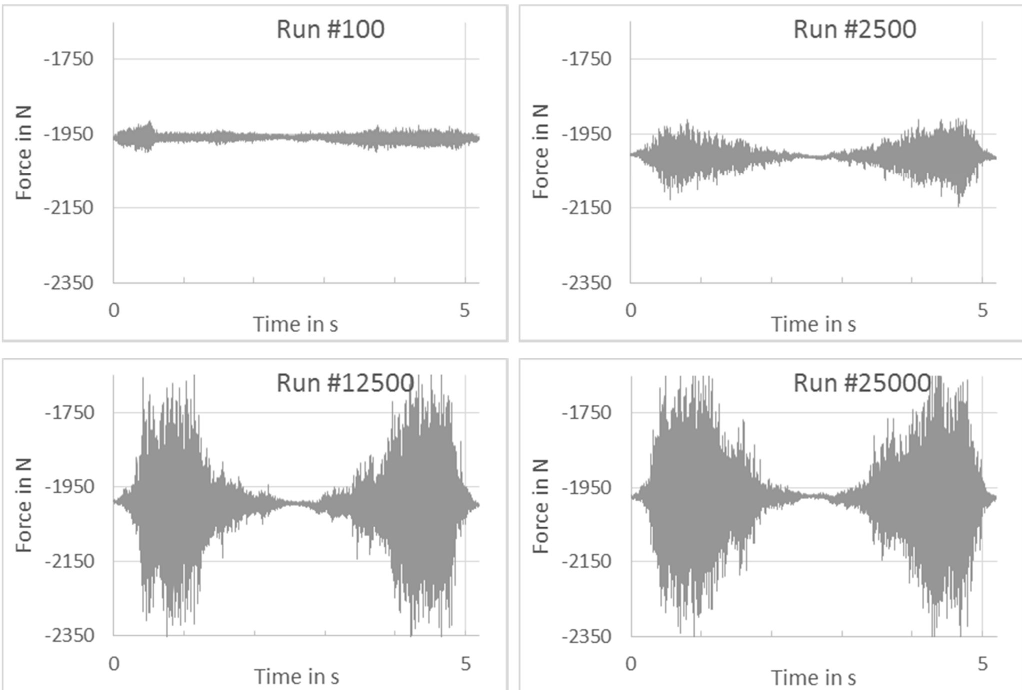

Figure 4: Vibrational patterns of various test runs

The causes for the vibrations and their strong intensification are analyzed in the following section. Possible causes for this usage are:

- ❖ Overload of the rollers due to excessive rotational speed or temperatures as well as insufficient lubrication and the resulting damages of the rollers due to material fatigue. [6],[7]
- ❖ Axial vibrations, which occur due to fabrication inaccuracies of the swinging brackets. [7]
- ❖ Development of run marks on the running surfaces of the rollers or the drive disk as a result of inconsistent pressure. [7]

Examination of the rollers for possible damage

If the rollers are exposed to unsuitable operational conditions like excessive rotational speed, the occurrence of particular damage patterns can be observed. In order to exclude these damages, the rollers are examined after the test. Figure 5 shows the raceways of the inner and outer ring as well as the rolling elements at the opened rollers.

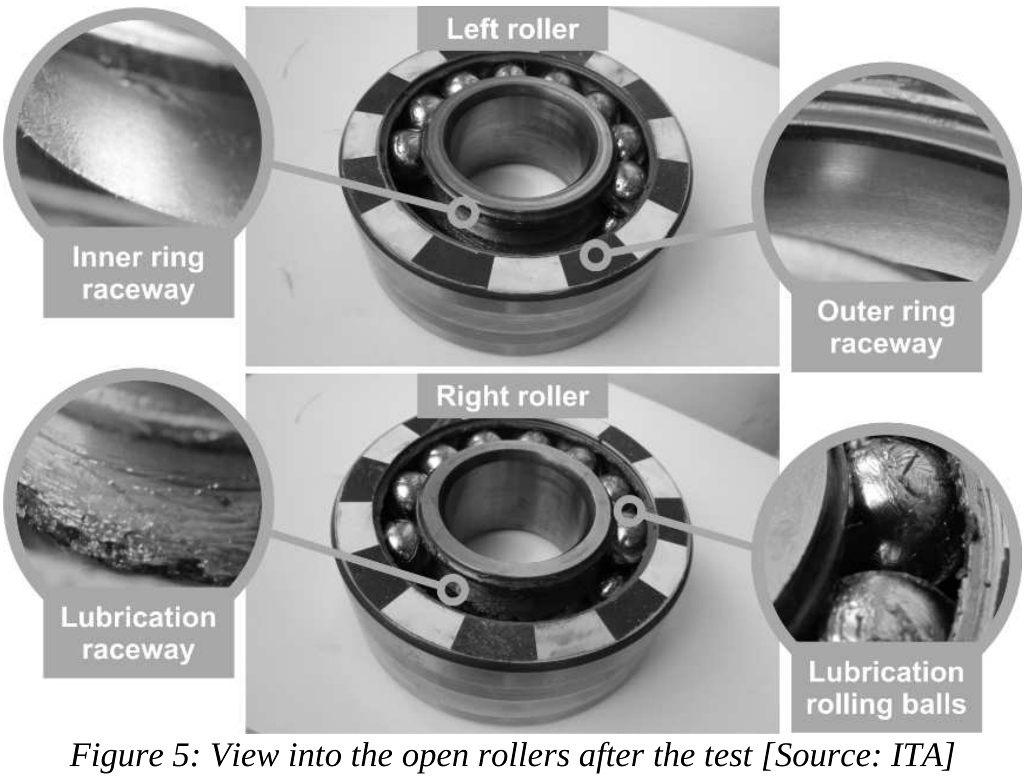

Figure 5: View into the open rollers after the test [Source: ITA]

There are no patterns visible neither on the rolling elements nor on the raceway surfaces of the inner and outer ring. There is no visible sign of damage resulting from material fatigue or attrition detectable. There is also no sign of foreign objects. Both rollers show sufficient lubricant after the completion of the operation test and the raceways as well as the rolling elements are clearly coated in lubricant. Thus, symptoms of material fatigue at the rollers are not the cause for the increase of vibrations in the course of the test.

Testing for axial vibrations

A proof for the occurrence of axial vibrations at the swinging brackets can be found by analyzing the sitting surface at the left roller's inner ring as well as the corresponding axis of the swinging bracket, which are depicted in figure 6.

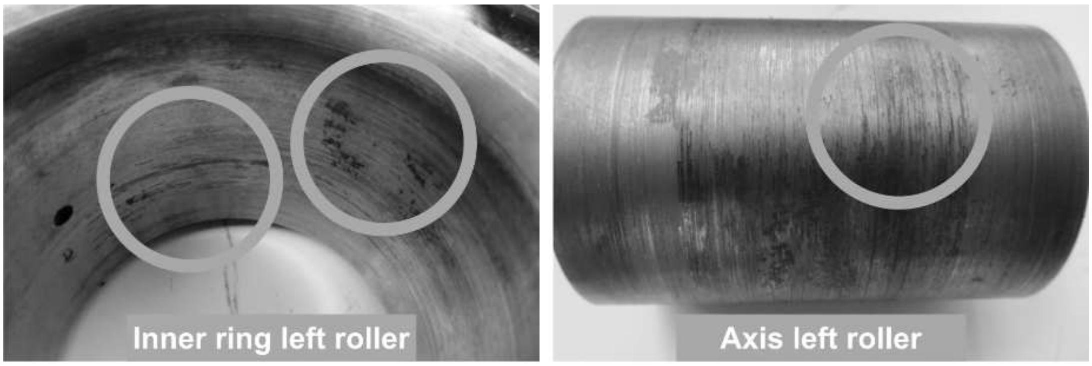

Figure 6: Fretting corrosion on the sitting surface of the left roller's inner ring as well as on the corresponding axis [Source: ITA]

Fretting corrosion can be found both on the sitting surface of the inner ring and on the surface of the axis. This corrosion emerges as the fit between the bore of the inner ring and the axis is too loose, which results in an unstable attachment of the roller. In order to examine this issue more closely, distance measurements between rollers and axes are conducted.

Examination of the swinging brackets

The swinging brackets at the roller test rig incorporate the rollers and are attached to the roller test rig themselves through a plain bearing. As the design of the swinging brackets is to be applied to the use in the Einstein-Elevator, it is also important to examine the swinging brackets as potential causes for the occurrence of vibrations. Figure 7 shows a swinging bracket along with a roller in the same way as mounted on the roller test rig. There, the spring, which is used to create the preload force, and the force transducer, which is used to record the occurring forces, are visible.

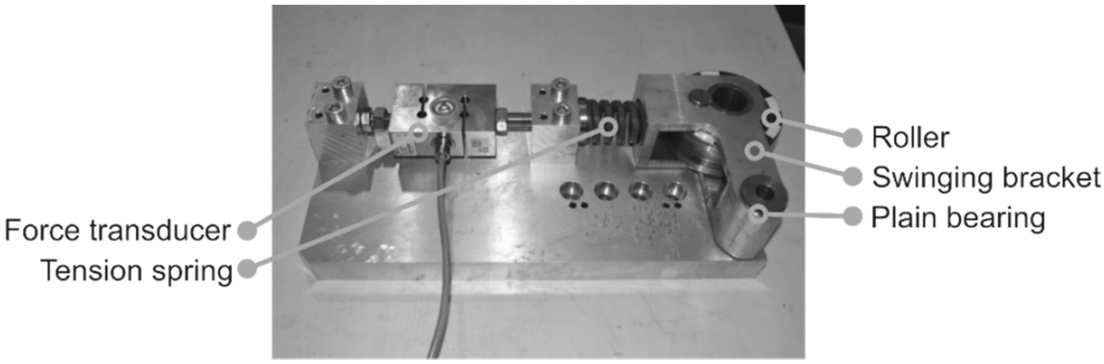

Figure 7: Swinging bracket with roller, spring and force transducer [Source: ITA]

In order to analyze vibrations at the rollers and the vibrations themselves after the completion of the operation test, measurements are conducted in the axial direction with the help of a distance measuring laser. In order to determine the behavior of roller and swinging bracket, three directly consecutive test runs are conducted. With their help, it is also possible to determine the behavior of the components when the direction is reversed. The left graph of figure 8 depicts the results for the right roller.

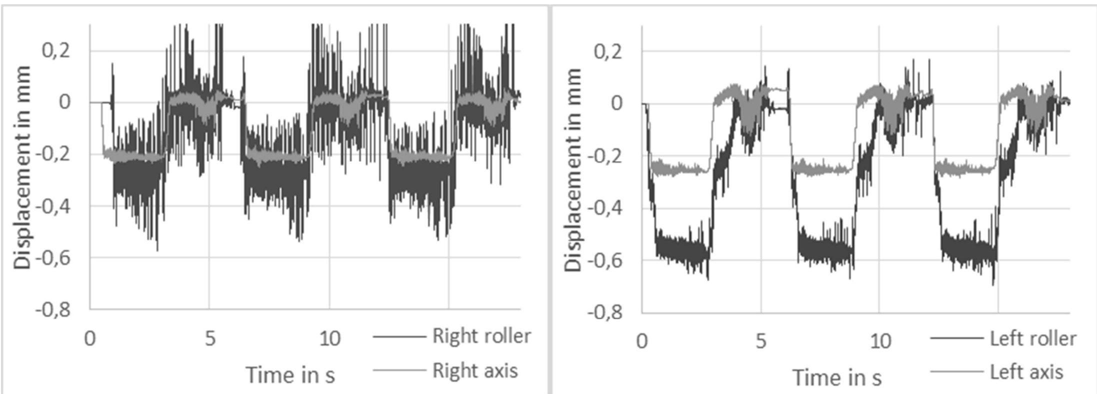

Figure 8: Axial shift of rollers and axes during three consecutive test drives

If the direction is reversed, it is possible to observe a shift of roller and axis at the swinging bracket. There, the components move about 0.2 to 0.3 mm in a short time, which corresponds to the figures, which were already determined prior to the beginning of the test with the help of a meter. Thus, the shift was not intensified during the test. As it is possible to observe this behavior for both components, it can be concluded that the shift is a result of the swinging bracket construction.

For reasons of comparability, the result of the measurement of the left roller is presented in the right graph of figure 8. Here, the roller's shift is noticeable, as it moves 0.6 mm, which is twice as far as the former roller. Additionally the return flow of this roller follows in a delayed manner. It also shows a bigger scope on the axis, which has been expected through the previous analysis of the sitting surfaces of roller and axis and the presence of fretting corrosion. However, an increase of vibrations in the course of the test phase was also not detectable.

The extraordinary increase of vibrations can only be traced back to a possible attrition of the components. Thus, for further analysis, the recorded force and shift patterns are finally evaluated through a frequency analysis.

Analysis of the vibrations

In order to analyze the vibrations, the fast Fourier Transform (FFT) is applied to the recorded force patterns. With the help of the FFT it is possible to decompose the recorded force patterns into the occurring frequencies and their related amplitudes. Thus it becomes visible, which frequencies have the biggest influence on the whole vibrational pattern. Ideally, these frequencies can be assigned to certain components in the next step in order to determine the source of the vibrations. Figure 9 shows the frequency range of the left roller.

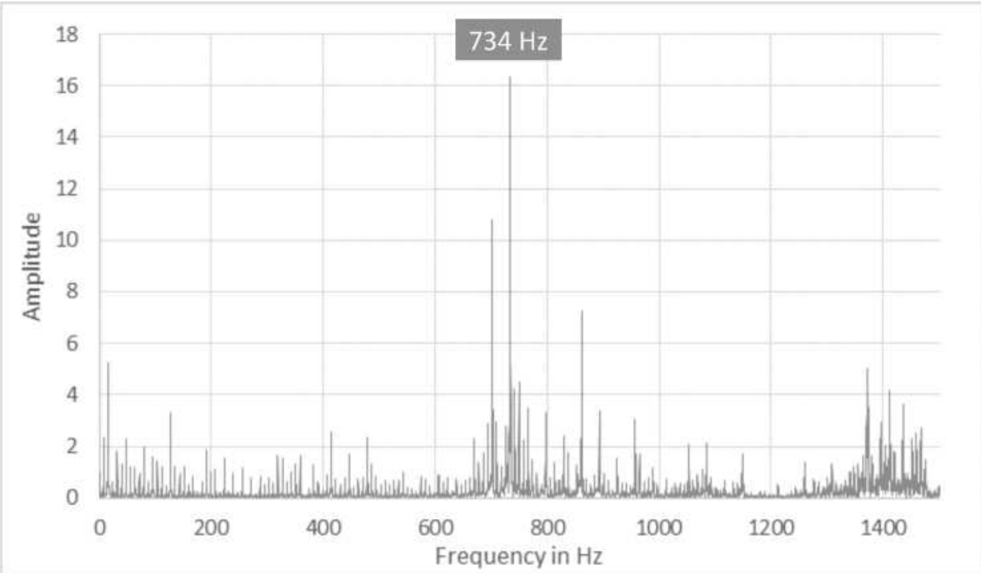

Figure 9: Frequency range of force values at the left roller, force values measured at a constant speed of 10 m/s

Peaks at 734 Hz are clearly visible. These peaks were already visible at the beginning of the test but intensified in comparison to other frequency parts during the course of the test and dominate the vibrational pattern. It is possible that the cause of the frequencies at 734 Hz is the roll off of the rollers. Figure 10 shows the drive disk’s running surface, which exhibits attrition after the completion of the test that is visible to the naked eye.

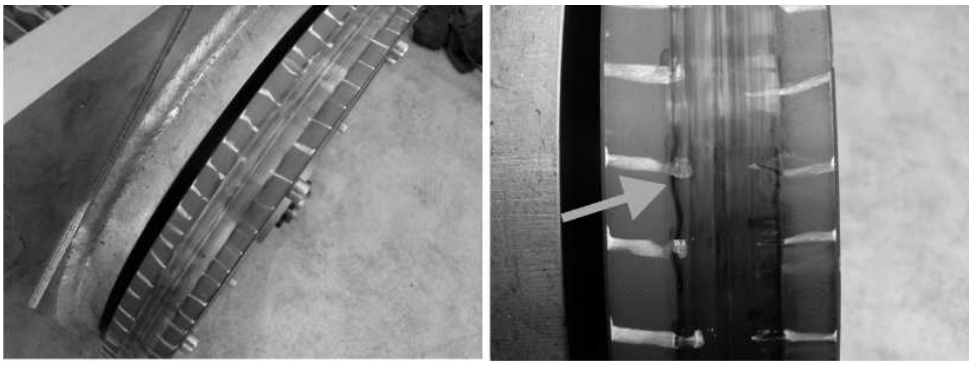

Figure 10: Running surface of the drive disk after the test [Source: ITA]

The attrition profile develops because of the spherical surface of the rollers. This works itself into the surface of the disk. Looking at the profile, which is slightly corrugated at the edges of the run marks, an already existing unevenness can be guessed. Thus, it can be concluded that the rollers move in an axial direction during a test run. The chalk marks elucidate the visible waves so that 92 waves are visible on the entire perimeter. Taking the rotation speed of 10.02 m/s and the disk's rotation frequency of 7.98 Hz, which can be determined directly from the data of the internal rotary encoder, it follows that the rollers roll over 734 waves per second. This number directly corresponds to the dominant frequency of the force transducers' range.

It can be assumed that the axis of the drive disk does not run exactly parallel to the axes of the rollers, which is schematically illustrated in figure 11.

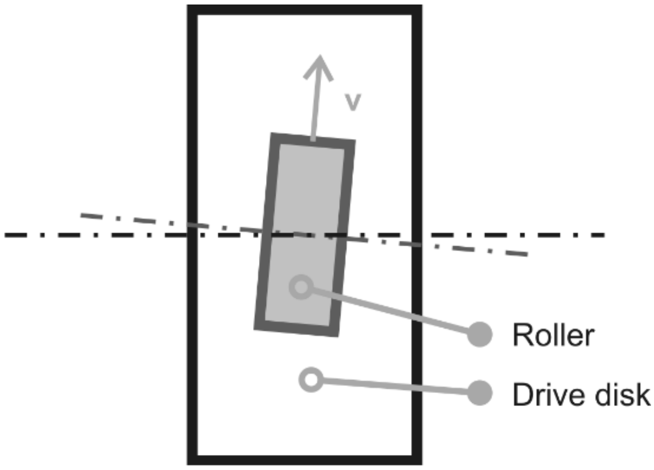

Figure 11: Tilting of the axes of drive disk and roller, view on the running surfaces [Source: ITA]

It is for that reason that a tilting in between the components occurs, which, during operation, results in the rollers being driven sideward at the rotation of the drive disk. The stiffness of the swinging brackets works against this axial movement and pushes the rollers abruptly back into a middle position at regular intervals when the frictional force between the running surfaces is overcome. As the sideward deviation is only dependent on the way of the rollers during a rotation, an even and undulated attrition profile occurs on the running surface of the disk, which is independent from the speed of the rotation.

Summary of results

The recorded data, which was gathered during the operation test, show a significant increase of vibrations in the frequency area of 734 Hz. As the running surface of the drive disk is the only component showing visible attrition symptoms, these vibrations can be reduced to the unevenness, which occurred on this surface.

After the completion of the test, it can be further concluded that the rollers are also suitable for the exceptional application in an Einstein-Elevator. Even after the completion of the annual performance of 25,000 test runs there is no attrition visible at the rollers. The lubrication is also sufficient for the expected abrupt load change.

Vibrations occur through an axial scope of the swinging brackets and rollers, which supports an uneven abrasion of the guide disk's running surfaces. At the rollers, axial movements occur as the result of a loose fit of the rollers on the axis. Vibrations at the swinging brackets cannot be completely avoided due to construction. However, it is possible to reduce the vibrations through a double-sided clamping of the swinging brackets on to the plain bearing. In order to reduce attrition at the running surface of the guide, a harder material could be used. [7]

CONCLUSION

Roller guides for the linear operation and the gondola with the test chamber are great influence factors for the accuracy of tests with microgravity in the Einstein-Elevator of the Hannover Institute of Technology.

In order to analyze the rollers, a roller test rig is used, in which two rollers are strained with the speed profile of the Einstein-Elevator through a bigger drive disk at the same time. In order to test whether the rollers are suitable to the use in the Einstein-Elevator, they undergo an operation test with the help of the roller test rig, in which they are exposed to the later expected annual performance in regular operation. Then, the recorded vibrational patterns are analyzed. In the process of the test, a strong increase of vibrations is observable, which can only be a consequence of attrition on one of the components. The analysis of the rollers does not show any signs of material fatigue, which shows that they cannot be the cause. Further measurements show that the cause of the vibrations lays in the attrition of the drive disk's running surface, which are to be rectified in the future through modified fits and tolerances.

Thus, it can be said that the rollers are generally suitable for the use in the Einstein-Elevator. After the completion of an annual performance at the roller test rig, there are no symptoms of material fatigue observable. Thus, an acceptable durability can be expected. In comparison, the rollers' influence on the occurrence of vibrations is very low. In order to reduce the occurrence of vibrations, it is necessary to examine the incorporation and bearing of the rollers separately as well as the guide and its surface and, if necessary, take steps for adjustments.

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