DeMaMech_2005_MaiOhno_Report

1. Personal Data

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2. Executive Summary

At first, I stayed in the Netherlands from 23rd august to 6th November. In Technische Universiteit Delft, I took some courses; English, Gas turbine, Engineering dynamics. I made some friends, and could know different culture, lifestyle through these lectures. Besides, I lived with some international people, so that I had good opportunities to speak in English not only in university but also at home. At the end of staying in Delft, I became a person who doesn't hesitate to talk to foreigners.

Then, I moved to Belgium on 7th November. In Katholieke Universiteit Leuven, I studied about ' balancing of a micro-turbine rotor'. Because this study area was very new for me, I learned many things from a teaching assistant, experiments and readings. Also I had good experiences, for example, to find an accommodation by

myself, to make friends in my dormitory, to travel a lot of places. Conclusively I enjoyed whole staying in Europe very much. I became stronger mentally than before.

3. Travel Schedule

22/08/2005-06/11/2005	Technische Universiteit Delft, the Netherlands
07/11/2005-01/02/2006	Katholieke Universiteit Leuven, Belgium

4. Research

Title: Dynamic balancing of a micro-turbine rotor

1.Introduction and the purpose of this research

The Power MEMS project of KULeuven aims developing a fuel-based power generation system, based on a micro gas turbine. The total system should measure 1 dm^3 and consists of a compressor, combustion chamber, turbine and compressor. It has a power output ranging from 100 W to 1 kW. The rotational speed is 500.000 rpm for a compressor diameter of 20 mm.

A rotor rotating at high speed is useful in some area, for example, electric motors and generators, turbines, and so on. Such kind of rotor is also demanded in the PowerMEMS project. But it is difficult to rotate at high speed without vibration, so the vibration has to be removed as much as possible. In this research the task is to balance a rotor supported on air bearings. After balancing the rotor should rotate at a higher speed (nearly 100,000 rpm). Moreover, some simulations are done using software, and compared with testing results.

2.Balancing techniques - the influence coefficient method -

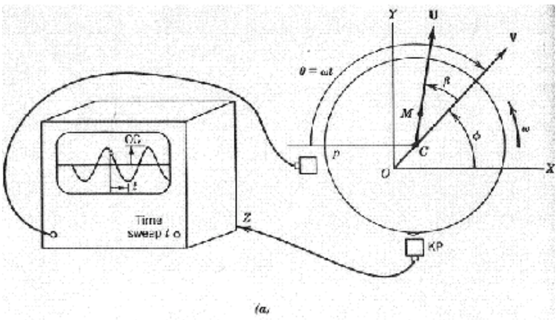


Fig.1 Measurements for balancing by the influence coefficient method

Only rigid-rotor balancing techniques will be discussed here. Two balancing planes are necessary to compensate for static and dynamic imbalance. Fig.1 shows a model of the measurement setup needed for balancing by 'Two phase influence coefficient method' (U: imbalance, V: response of imbalance, M: mass center). By adding a correction mass foils (Fig.2) on planes, the balance of rotor is compensated. Vibration transducers and a keyphasor transducer are required. This equipment measures vibrational amplitude and phase. Using these values, MATLAB calculates the desired mass values.

Fig.2 Correction mass foils

3.Setup

The test setup mainly consists of two disc rotor supported by a split aerostatic air bearing. Correction mass foils (with a thickness ranging from 40 μm to 500 μm) are used to correct for the detected imbalance.Testing was started with the existing setup as shown in Fig.3. The new test setup allows a more accurate and more consistent detection of the imbalance response.

4.Simulations

4.1. Calculation of the critical speeds for different bearing stiffnesses

Using 'Unigraphics NX 3.0', we got some data of critical speeds without gyroscopic effect. For conical mode, thrust bearing stiffness has more influence than journal bearing stiffness. For cylindrical mode, there is no influence by thrust bearing stiffness as shown in Fig.4.

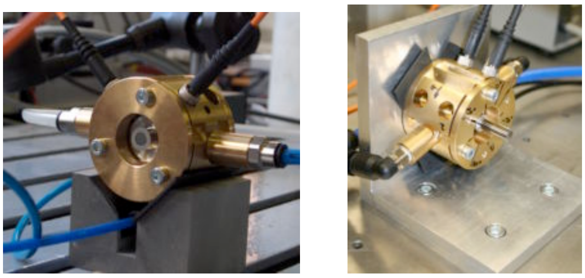


Fig.3 Total setup with bearing pressure supply, turbine supply and fiber optic displacement probes (left figure before modifications, right figure after

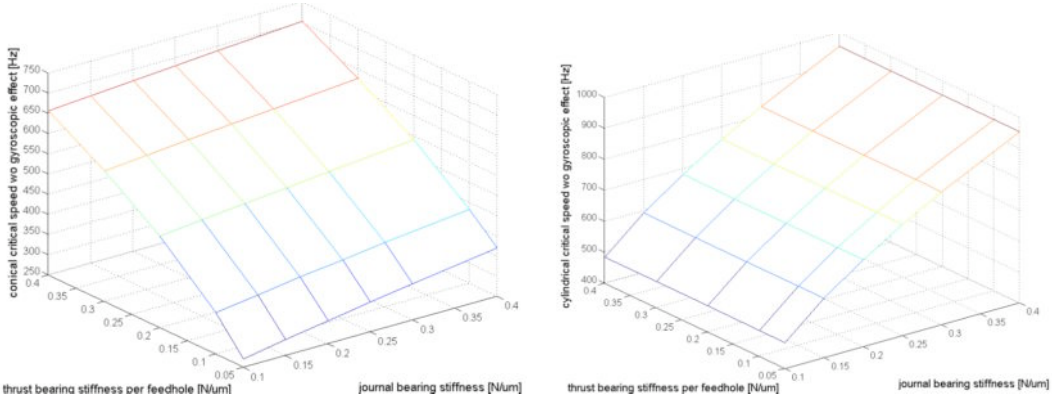


Fig.4 Conical and cylindrical critical speed without gyroscopic effect.

4.2.Air bearing calculations with MATLAB

Using 'MATLAB', we calculated some (static) stiffness estimates for different values of the clearance. Fig.5 gives an overview of the results for an aerostatic journal bearing with diameter 6 mm, a length of 3 mm. The bearing has six feedholes of 0.3 mm. Fig.6 shows the thrust bearing stiffness per feedhole for different bearing gaps and supply pressures. The thrust bearing has an inner diameter of 8 mm, outer diameter of 20 mm and has six

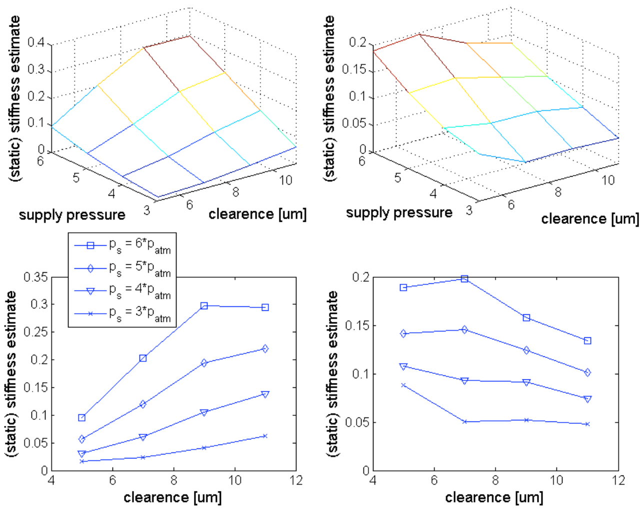


Fig.5 Journal bearing static stiffness estimate for different values of the clearance and supply pressure. (left figure: eccentricity = 0, right figure: eccentricity = 0.5)

feedholes of 0.3 mm. To calculate thrust bearing stiffness values, it is no need to consider about eccentricity.

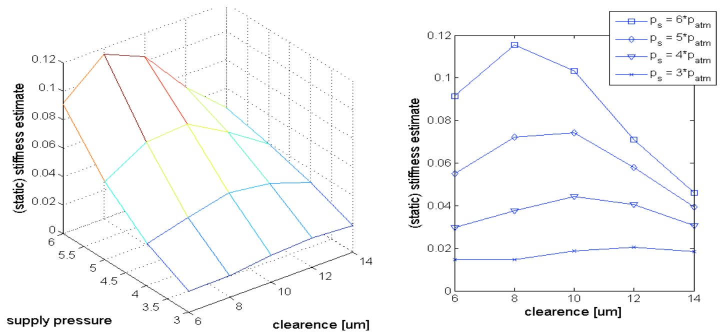


Fig.6 Thrust bearing (static) stiffness estimate for different values of the clearance and supply pressure

5.Testing

We used 'LabVIEW' to acquire the data, and 'MATLAB' to analyze the measurements to extract the synchronous vibrational amplitude and phase of both transducers. The eccentricity of the rotor disc with respect to the shaft is measured once at a low speed. After this calibration only the response to imbalance is measured. The measurement results shown below are expressed in mV (3 mV=1μm). When starting the experiments with the new L-shaped support structure, the rotor seems to be influenced by the vibration of the support structure. A rubber layer of damping material is added between the rotor system and the support structure. After adding this rubber layer, the amplitude of vibration and the resonance frequency became smaller.

5.1. Two plane influence coefficient method

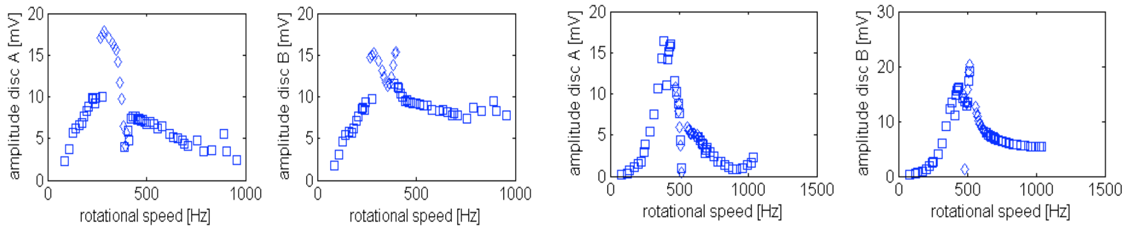
With the improved test setup including the keyphasor signal as triggering source, balancing by the two plane influence coefficient method was tried. After some test runs at 500 Hz the following correction masses were calculated: a foil of 40 μm at -135º together with a foil of 80 μm at -165º at rotor disc A, and a foil of 200 μm at -15º at rotor disc B.

With this condition, major improvements could be seen. At first, it was confirmed that there are two critical speeds on this rotor. This is corresponding with the analysis with Unigraphics. In addition, it could rotate at higher speed more than 1.5 kHz (nearly 100,000 rpm).

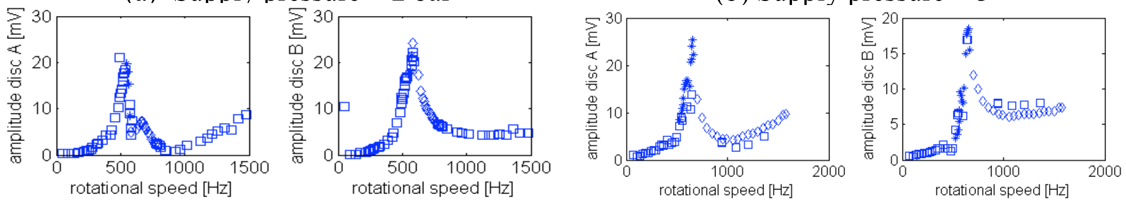
The residual vibration level at supercritical speeds equals 6 to 8 mV. Conversion to amplitude in micrometers gives ca 3 μm. This is nearly one third of the clearance value of the journal bearing. Fine balancing at supercritical speeds could reduce this level further yielding a lower frictional loss in the air bearings.

5.2.Effect of different supply pressure levels

Fig. 7 (a) (b) (c) (d) and table 1 show the effect of a different bearing supply pressure on the critical speeds. At a decreased supply pressure the amplitude peaks at a lower speed. The maximum value at critical speed increases with supply pressure. This can be explained by a less optimal damping value at high bearing supply pressures.



(a) Supply pressure = 2 bar (b) Supply pressure = 3



(c) Supply pressure = 4 bar (d) Supply pressure = 5

Fig.7 Runup to maximum speed at different supply pressures

	2 bar	3 bar	4 bar	5 bar
mode 1	230 Hz	440 Hz	540 Hz	570 Hz
mode 2	420 Hz	530 Hz	650 Hz	655 Hz

Table 1. Critical speeds at different supply pressures

6.Comparison of the result from testing with simulation

For a supply pressure of 5 bar we can guess out of Fig.4 that the linearized thrust bearing stiffness should be 0.3 N/μm and the journal bearing stiffness should be 0.2 N/μm. Then, by looking at Fig.5, the journal bearing clearance is expected to be 7μm. This matches with the expected value. However, the inspection of Fig. 6 does not yield a reasonable clearance value of the thrust bearing. Experiments at other supply pressures yield the same conclusion.

It seems not possible to match both conical and cylindrical critical speed to a reasonable clearance value of journal and thrust bearing. This can be explained by the fact that an air bearing features a strongly nonlinear behavior. The Unigraphics simulations however only took into account linear rotor supports. The simulations done in MATLAB on the other hand resulted only in static bearing stiffness estimates. It would be more correct to calculate the dynamic stiffness values at synchronous speed. Moreover, the two rotor disc planes are never exactly parallel, even with the improved rotor.

7.Conclusions

When rotating of micromachinery at high speed, it is very important to keep the imbalance as low as possible. We used one of the balancing techniques 'two-plane balancing method with influence coefficient' to compensate for the imbalance of a rotor. The balancing experiments clearly resulted in a reduced rotor vibration. Also simulations with MATLAB and Unigraphics are done. The difference between these simulations and the test results can be explained.

5. Exchange student life

Delft

I lived in Delft about 2 months with international girls, from Australian Portugal, Swiss, and Italy. This environment was really nice to practice English, to have a fun, and not to feel lonely. And there were opportunities to meet other international friends through classes or joining a party and so on. There were also some Japanese exchange students. I often went out, ate dinner and had a party with these friends. We shared many different feelings and knew another culture from each other.

I felt that Dutch people have very cheerful character and I liked it. They invited me to eat Dutch meals and to go out some places for sightseeing. In terms of learning English, living in Delft was very good for me because there were many opportunities to speak in English with foreigners (especially Dutch people speak English very well).

I learned what important is to talk to someone without hesitation more than to speak English fluently. At the end of staying in Delft, I became a person who doesn't hesitate to talk to foreigners.

Leuven

In leuven, it was hard to find an accommodation. It took me 4 days. I visited the Housing Office many times, and then finally I got a room. I lived in a dormitory where about 45 people live. I sometimes played table tennis with friends in a dormitory. We had a breakfast together on the day of Sinterklaas, and had a Christmas party. Majority is Belgian, so I could see typical life style of Belgian people. I think that their characters are similar to Japanese like shy or not so noisy. It took some time to get friendly.

While eating dinner in a common kitchen, they speak in Dutch. So, I couldn't understand what they were speaking. At first, I was a little bit shocked. But of course, while talking with me, they speak English. Other international students who lived there speak in English of course. I got used to living there in a month.

During weekend, almost all Belgian students go back their home so that the dormitory is empty and quiet. Because I didn't like stay home during weekend and Belgium is not so big country, I often took a one-day trip in Belgium. Also during winter vacation or some weekends, I went to other countries in Europe.

At university, I did research that was very new topic for me, so I started with reading papers. The time for the research was less than 3 months. It was short to learn a new topic and write a report, but it was good time and new challenge for me.

Generally

As mentioned above, I totally enjoyed the life in Europe. Everyday I found something new. I was interested in everything new. I learned not only about studying but also how to fit in a new environment, how to communicate with foreigners and so on. Now I know that there is no need to hesitate to tell what I want to do. And I can do it.

6. Summary

It was really nice experience that I lived in Europe 5 months. Everything was new for me, and I was enjoyed all. Of course some problems happened while staying Europe, but I could solve them by thinking well and by moving into action. I will really never ever forget about the life and the experiences in Europe and the people whom I met there.