DeMaMech Exchange Project

Report

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1 Personal Data

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Chapter

2 Executive Summary

DeMaMech Exchange Project is a program where European students go to Japan and Japanese students go to Europe for study purpose. All students are studying in the field of Design and Manufacturer in Mechatronics. Students can apply for a period of five or ten months to do a small research or master thesis.

I had the opportunity to go to Osaka, Japan, for ten month from September 2004. I found my Master thesis project at Takeuchi's Labaratory Japanese Labaratory, where they offered me a challenging project. In this Labaratory they study and develop CAM System for Multi-Axis Control Machining. My project was about improving the accuracy of a parallel kinematics machine tool.

In Japan I experienced immediately the differences between Japanese (Asian) and Dutch (European) culture. The language was difficult, and studying at a Japanese University is totally different. Group mentality is strong in Japan where Europeans are more used to induvidual approach. I also expected a more "high-tech" Japan, but streets don't look like that and I experienced a lot of paperwork at public offices. Japanese are hard working, good motivated people, and little shy, but many with a warm heart. So it was very nice to live there.

Research was done during the entire ten month, and besides that I attend succesfully the first level of Japanese at the university. Many Japanese people don't speak English very well, so for more social contact I wanted to learn more Japanese. Now, I am able to have a conversation. Researching was sometimes difficult due to language barrier but sometimes very nice with a lot of freedom for me as " foreigner". They understood that I was used to work in a different way. I had to improve the machine accuracy of a Parallel kinematic machine tool. Therefore, the accuracy was investigated with machining experiments. Besides that a mathematic model has been build, so I was able to analyse the influence of several possible error sources like assembly and gravity related errors. Finally, a solution was proposed to reduce the error for machining. However, due to machine problems this couldn't be finished completely. My temporary results I presentated at Toyoda Machine Works and I wrote a paper about my research, which I may present at IMCT conference at Kuala Kumpur December 2005.

Life in Japan was tough in the beginning, I had to get used to the Japanese culture. Later I enjoyed it more and more and made more friends, Japanese and with other people from all over the world. Changes given me by especially Prof. Dr. T. Tomiyama, gave me unforgetable and worthy experiences and moments for the rest of my life. I can do nothing else than thank the organising people and recommand everybody who gets the opportunity to join this project to go!

Chapter

3 Travel Schedule

15 September 2004	Amsterdam – Osaka (10.5 hours) *The flight was a direct flight between Amsterdam and Osaka with KLM. The ticket offered was a special student ticket with an open return date within one year.*
29 August 2005	Osaka – Amsterdam (12 hours)

Some travel advices:

On most flight there is limitation in weight you can bring with you. Sending things by sea mail gives you the possibility to send many kilos cheap from Japan to Europe. (20 kilo – 10.000 yen = 70 euro). It will take about 4 or 5 weeks but who cares about delay of your winter jacket or some study books?

Traveling in Japan is easy by train. Also for long distance the fast Shinkansen is an easy but expensive solution. Why don't you take a cheap bustrip! At Osaka university campus Travel Agency or another one you can find cheap bus trip from Osaka to many places in Japan. For example to Hiroshima about 8.000 yen (60 euro) to Tokyo it costs about 9.000 yen (65 euro) return, while shinkansen train costs you 26.000 yen (200 euro).

For local trains you can buy a prepaid card, it not cheaper but it more convenient instead of buying all the time a ticket from the ticket machines.

Some nice places to visit are:

Tokyo, *beautiful buildings, crowded streets, eating and shopping everywhere and other DeMaMech students / friends.*
Nara, *located close to Osaka where you can find "Nara Park". With many old temples and shrines, very nice to walk around and see the old beauty of Japan.*
Kyoto, *a big city that is very famous for it's traditional Japanese culture. Many temples in a city like all others. You can enjoy " temples watching", some nice festivals, and the old town "Gion".*
Hiroshima, *city of the atomic bomb attack. You can see the momuments and a imprssive museum. Close to Hiroshima you can find himejima a very famous and beautiful temple on an island*.

Futhermore, you can enjoy the nice beaches in Japan, musea if you like, the huge theme Parks (like Universal Studios Japan), or hiking in the mountains. So, for travelling there are many nice possibilities

Chapter

4 Research

Introduction / Summary

Before I left from Holland to Japan I found a nice challenging project at Osaka University in Prof. Dr. Takeuchi his Laberatory. It was important to get clear what they expected from my side, and what the project was exactly about. Therefore, be prepared and know what you have to do. Japanese thesis work is different than the European so understanding of each other's method is required for a good start in Japan.

My laboratory is researching "Development of CAM System for Multi-Axis Control Machining". Sevaral multi-axis machines are available for research, in my case a Parallel kinematic machine tool, shown in Figure 4.1

Figure 4.1: HexaM, from Toyoda Machine Works. Japan

Parallel kinematic machine tools are a new promising concept in the search for new machine tools. Interesting application is in material removal that compels high speed and accuracy requirements for nowadays production. Those machine tools deal with the typical accuracy problems, which come with parallel machine structures. Especially, accuracy improvement of the non-uniform position errors is emergently required as the first step of machining improvement.

In this research, the focus was on the investigation of the geometrical errors, gravity and the calibration related machine errors. A kinematic model is used to investigate and simulate the influence of several error sources on machining.

Using simple milling experiments, the errors after machining were investigated for several milling cases. Using the gathered knowledge of experiments and simulations, an error prediction model has been realized to calculate the error compensation vector, which can be used in CAM environment. In that application, the tool path is recalculated, using an error prediction model. Every single machining coordinate is changed using the error compensation vector. So, improving of machining accuracy with error compensation, by use of cutting conditions and position knowledge, has a possibility to improve the machine accuracy without changing the machine structure.

Title

"Improvement of machining accuracy for parallel kinematic machine tools using error prediction and compensation for CAM application".

Modeling of the machine kinematics

To solve the problems described above, modeling is used to simulate the influences of several error sources in the system. Mainly focus was on analyzing the geometrical error sources, the influence of gravity and also the influence of machine calibration. The simulations gave an idea how several error sources contribute to the error in the workspace.

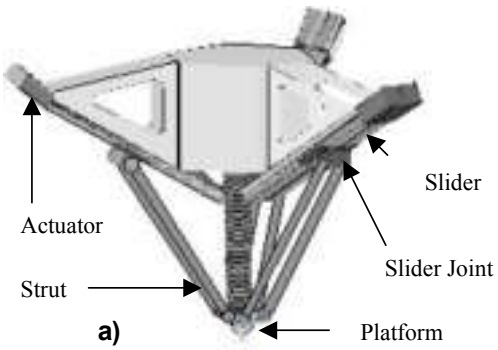
The used model consists of six pairs of strut-slider combinations shown in Fig. 4.2.a. Using the kinematic model shown in Figure 4.2.b, the silder positions can be calculated using the tool-tip position (X), or the tool-tip positions can be calculated using the slider positions. These calculations are known as the inverse and forward kinematics of the machine mechanism, respectively.

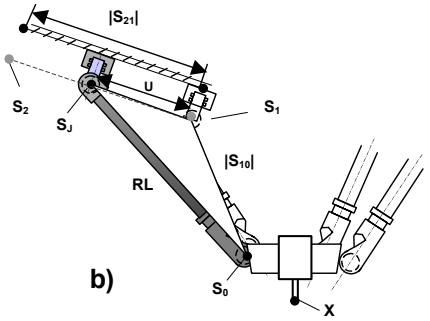
First error source was geometrical errors assumed in the mechanism. Due to, for instance, machine manufacturing-, assembly-, or calibration errors. Geometrical errors were added to several elements in the six kinematic chains, and then the tool tip error was simulated for many positions and orientations.

Second error source was gravity assumed on some machine elements. See Figure 4.2.c. With this model it was possible to predict the gravity related forces in the mechanism. In the analysis of gravity, the following elements were investigated: Strut with limited stiffness in axial direction; ball screw spindle with axial compliance; and ball screw spindle with bending.

The error-vector-field in case of several geometrical related errors is shown in Figure 4.3.a, and the errors due to gravity are shown in Figure 4.3.b.

The third error source, which was investigated, is errors due to the calibration method. The machine was delivered calibrated. The calibration method, which was used for this machine was studied. This method uses a mathematical representation for the machine. This model was compared with measurements executed for the calibrations. Differences found where always addressed to geometrical errors, for example strut length or slider angle. If more error phenomena are assumed, then a more accurate calibration can be realized. Therefore, the used calibration is assumed to lead to errors. Furthermore the measurements didn't cover the whole workspace, which can lead to border deviations after calibration.





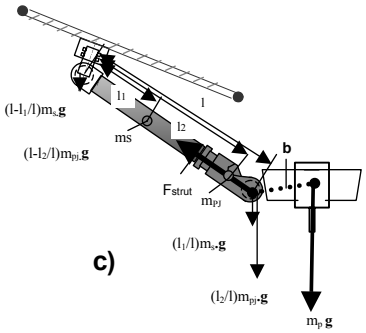


Figure 4.2

Since all errors are adressed to geometrical errors, errors looking like the geometrical errors can exist, similar to the simulated geometrical errors shown in Figure 4.3.b.

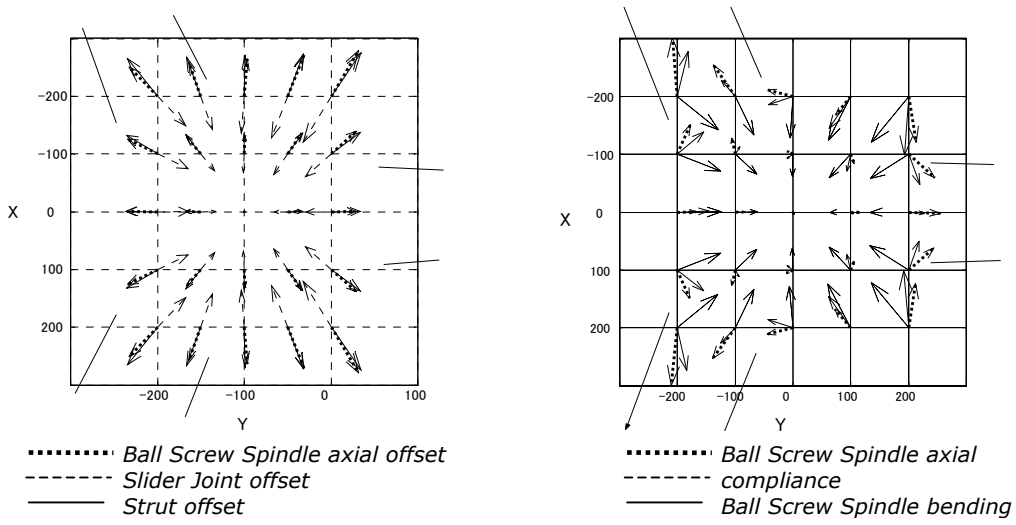


Figure 4.3: a) Geometrical offset errors *b) Gravity related errors*

Experiments

Experiments are necessary to investigate the errors in the workspace. Furthermore, to suggest which error sources have to be included in the error compensation model, the measurements data have to be compared with the simulated error sources. The experiments consist of milling of circle in the xy-plane. Figure 4.4 shows the experiment 1-5. Important aspect of experiments is the choice of the cutting conditions. To create a high accuracy result, the cutting settings are chosen in such way that there are low cutting forces during cutting which doesn't influence the total error so much.

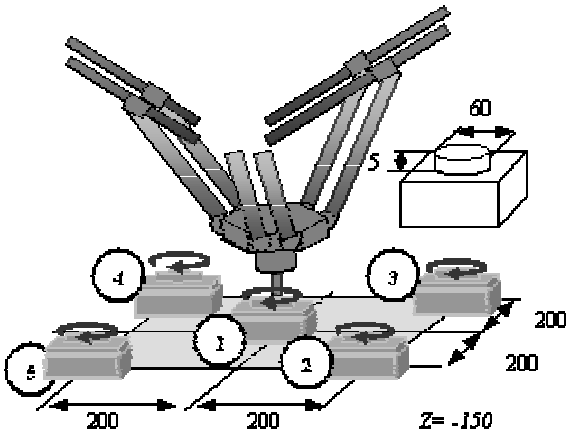


Figure 4.4: Five milling experiments

A calculation show that by the used cutting conditions the influence of cutting forces is too small to have tremendous influence on the experiments.

Differences between machine and measuring temperature will lead to deformation. Due to thermal expansion, a kind of scaling effect of the workpiece is assumed. For small temperature differences, the errors are limited.

The machined products are measured using a 3D Coordinate Measurement Machine (CMM, Mitutoya BHN-305) with an accuracy of 4+((5*l) /1000) µm. Where, l is the length of the measured line. In Figure 4.5 the measurements of the five machined

products are shown. The error is determined using the radius of the measured circle, compared with the programmed circle. In general, it can be said that the error is directed out of the centre of the machine workspace.

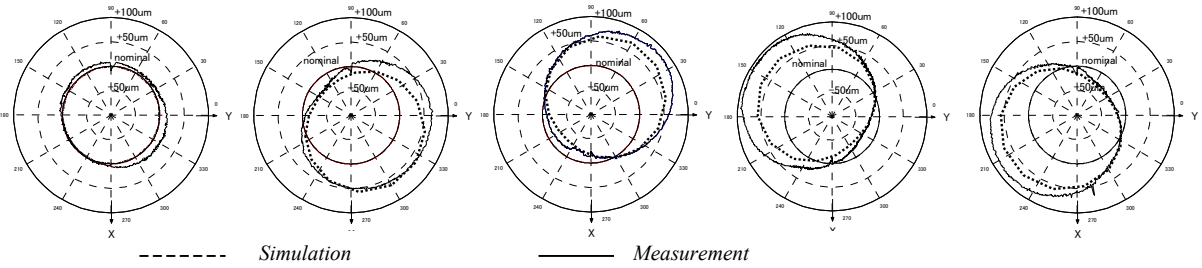


Figure 4.5: Measurement and simulation results for experiment 1-5

Error compensation

CAM is a software tool, which generates mainly, based on a CAD model, the machine instruction for the tool movements. In CAM software, all necessary cutting conditions are also defined, and therefore all this information is also available for error calculations. The existing CAM program, which already includes collision avoidance between tool and workpiece, will be extended with error compensation. In this CAM program, the tool path is defined, using individual cutting points and a linear interpolation motion along all these points. Error compensation is realized with recalculating these "uncompensated" points to "compensated" points. The machine has a very good repeatability, which means that higher accuracies can always be repeated with a good error prediction model. Figure 4.6 shows the flowchart for the calculation of the "compensated" error points.

To prove all assumptions, experiment 2 is repeated using error compensation. Figure 4.7 shows the uncompensated together with the compensated result.

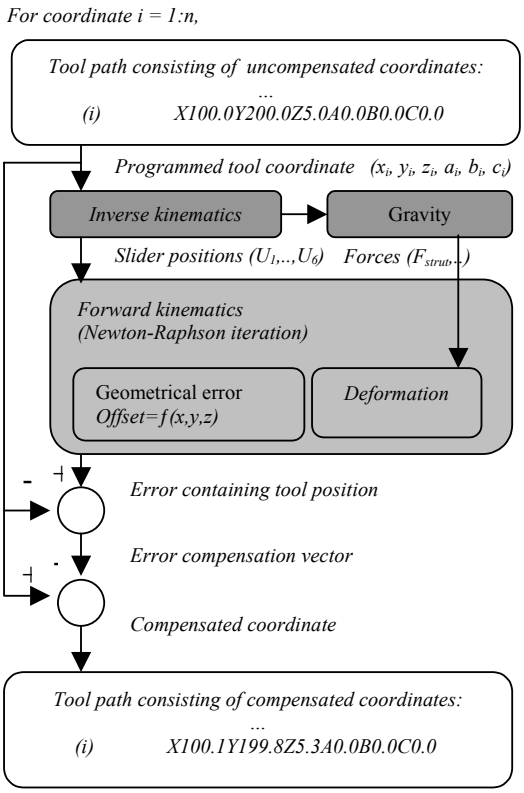


Figure 4.6: Error compesation flow chart

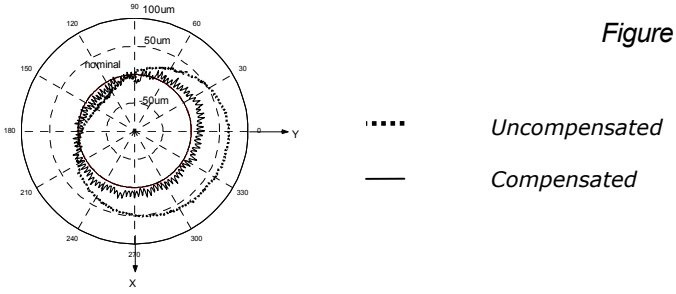


Figure 4.7: Error compensated product

Chapter

5 Exchange Student Life

University Life

Labaratory

Working at a Japanese university is different in many things compared to European University. Students work long days, from 10 a.m till 9 p.m. was more normal than exception. While we are used to work with an as high as possible work efficiency, Japanese students take it easier during the day. It is not strange to experience that they are reading Manga, watching movies or take a nap for 2 or more hours. But, nevertheless they can work hard to get good research results. Students organise a couple of times during the year parties were they go somewhere for drinking, or do a BBQ at the university. Japanese students even at good universities have a lot of problems with speaking English, and they are naturally shyness don't help them a lot with that. Some do speak good English especially the professor and other staff members, so be aware of that.

Their study method is also different. Japanese student enter the labaratory in their 4th bachelors year. Then they start their research to get their bachelor's degree. After that most students continue in the same Lab. With the same subject to finish the two master years. Allmost all students therefore are researching in the Labaratory while in Europe more students go to companies. The professor and his assistants are intensively involved in the student's researches. Compared with European research style the Japanese student has less freedom to solve the problem.

Students eat their lunch in the universities cafetaria or they buy a lunchbox to bring to the lab.

Other Exchange Students

Normally you are not the only exchange student, I had a good time with other students of the DeMaMech exchange program. We lived in the same dormatory and ate many times together and went out in weekends and saw many nice places in Japan together. Especially the first period you need those " Europeans" around you. The cuture and language barrier between you and the "japanese" can be big.

Besides the DeMaMach students in Osaka there was a big group of Osaka University Exchange Students. They came from all over the world and they follow a special program at the university. Our coordinator informed us about their activities, like Japanese language course and so I met them often. Since Japanese students are not used to live a studentlife like most of us, you cannot expect so much of going often out with them to drink a beer in the weekend or so.

Therefore, I did many things with those students and had a really great time with them.

Social Life

I lived in a international dormatory, 15 min. biking from the university. There lived many Chinese and other Asian people. It was difficult to get in contact with those guys. Most didn't speak English and lived very induvidual or in "chinese groups". There were also dormatories in Osaka with more European students; there it's easier to meet nice people. Don't expect a high-tech Japanese building, imagine just a old-fashioned student complex that's how it is.

Near the dorm we could find a small shopping mall where we could go for shopping or dinner. Be aware Japanese supermarkets are relatively expensive esspecially vegatables and frutes.

Getting around we could use the train to go downtown. The train network is very convenient and it's easy to use the train. Don't hazzitate to ask if you are not sure, Japanese are very helpful people. There are nice places to scroll around in the weekend and to get some nice Japanese food.

Osaka and the cities around have many nice things to offer for a day site seeing. Famous are Kyoto and Nara for their cultural momuments. Osaka and Kobe have more modern attractions. Using your "lonely planet" or comparable sources will bring you everywhere you want to go.

Chapter

6 Summary

This exchange project has been well organised by the organising staff. Arranging the housing, the financials and the preparation week helped me so much, and without this I couln't had this experience. After the preparation in Delft, I was heading to Osaka with a little knowlegde of the language and a project idea.

Japanese University life has suppriced me. Students work long days, actually, it looks like they live in the labaratories. Most Japanese students don't speak English very well, but some and mainly the staff do. Japanese students start in their 4th bachelor year in a Labaratory and will also do there 2 Master years there. Therefore, they are researching a project for a long time. Our system is different and therefore research approached and progress is not always compareble. Students are helpful and "big" problems are solved in a group. Osaka University offers language courses and more social activities for foreign students, where I met many other exchange students. University Library doesn't have so many books in English, ofcoarse nowadays Internet in a good sources but I sometimes missed my good books.

Research was done in the field of CAM System for Multi-Axis Control Machining. I had to improve the accuracy of a parallel kinematics machine tool by use of CAM. I investigated the machine accuracy by simple milling experiments. Besides that I had to develop an error prediction model to predict the measured machining errors. This was done using a mathematical representation of the machine and added some error phenomena like assembly-, calibration- and gravity related errors to this model. Together with the experiments this model was "tuned" to predict the errors. Later experiments shown an nice error reduction.

Student life besides studying was very nice. Soon was clear to me that I couldn't has my social life with the students in the Lab. But I had company of 3 DeMeMech students (Michiel, Micheal and Frederik) and with them I had good fun and a nice time besides the study. We get in touch with many other exchange students at Osaka University and make nice friends there. Traveling was nice and convenient in Japan. I saw many nice places, cultural things and nature. Met nice japanese people, enjoyed the Japanese Kitchen, song many hours Karaoke, grap many sushi's from the kaiten-sushi-belt, used my bycicle everyday, and experienced my first earthquake!