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Application of the Impact Drive Principle to the Alignment of Workpieces on Rotating Supports

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Abstract: In this paper a new positioning method for cylindrical work pieces on rotating supports is studied. A work piece on a rotating axis is positioned by an impact drive mechanism (IDM) whose driving parameters are steadily updated by observing the object movement. The application of this actuator and the use of a multi-functional PC board for all necessary input and output operations such as e.g. data acquisition or wave form generation allow an alignment with a precision of less than 1μm in a relatively short time and at low cost compared to conventional methods.

Keywords: alignment , piezo actuator, positioning method, rotating supports

1. INTRODUCTION

Ultra high precision NC machine tools possess an accuracy in the nanometer range and serve to produce components for various micro electro mechanical and optical devices [YAM_95/2], [KAN_95].
On these machines the conventional self - centering jaw chucks or lathe collets are replaced by vacuum chucks, because the precision of conventional chucks is limited to between 10μm and 30μm. These vacuum chucks, which allow machining processes with a precision depending only upon the chuck surface quality (roughness, flatness), require the work piece to be centered after every removal. Therefore the problem of a precise work piece positioning on the rotating axis' or spindles arises.
The conventional method is to push the work piece which has to be centered using a tool of a certain mass to apply impacts. The smaller the inter - axial distance between the work piece and the chuck is, the smaller become the impacts which have to be applied. This adjustment method is virtually almost performed manually and only by specially trained technicians. It takes approximately 15 minutes to achieve a precision of about 1μm by manual alignment.
The problem of the work piece alignment in the center of rotating axis' with high precision requirements also exists on other devices as e.g. roundness testers. The aim of the presented work is therefore to propose an universal precise positioning mechanism in order to avoid the difficult manual positioning method as well as to decrease the positioning time significantly. Furthermore the precision will be improved to be less than 1μm.

2. POSITIONING METHOD

Several years ago the Impact Drive Method (IDM) was developed [HIG_87], [YAM_95/1]. Actuators utilizing this method are capable to move work pieces of relatively large masses or held by strong friction forces and to adjust them with an accuracy of several nm and in an unlimited range.
An IDM actuator consists of a main body to which a counter mass is attached by using an piezoelectric actuator or any other kind of actuator which is able to follow applied wave forms (e.g. voltage, current) with a proportional extension or contraction. Fig.1 shows the principle of operation for a piezo actuator driven IDM.

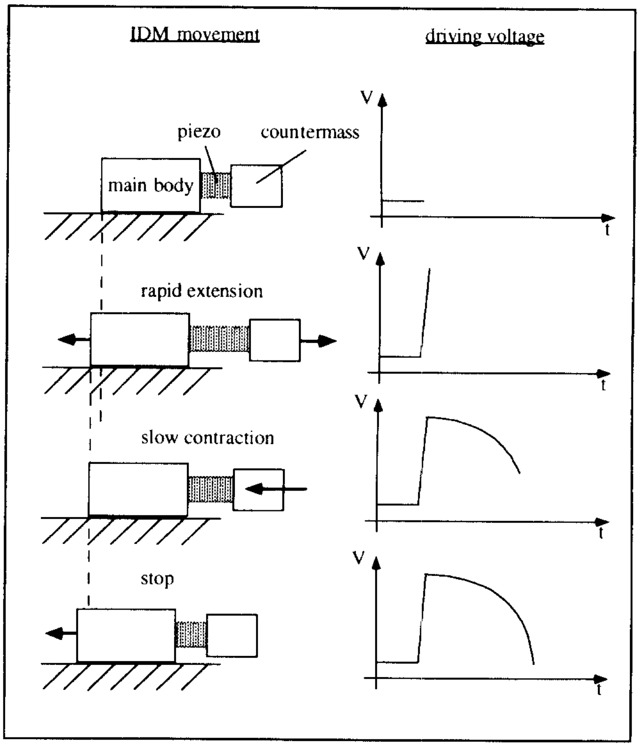

Fig.1 IDM: principle of operation

The main body is held by friction force which can be generated by springs, vacuum, magnetic force etc. or by the weight of the object itself.

The actuator has to perform a fast extension and a slow return which ends with a sudden stop. When the fast extension of the actuator takes place, the impact force generated by this extension moves both masses, overcoming the static friction between the main body and the support.
After the impact the piezo actuator contracts and moves the counter mass back while the main body keeps its position (slow return). The return of the counter mass ends with the sudden stop and therefore a second impact which causes the main body to move again.
There are two ways to apply the impact drive principle to the positioning of a mass:

- -The mass to be moved is the main body of an IDM and the piezo is directly attached to it.
- -A separate IDM consisting of main body and counter mass is applied and pushes the mass to be moved.

The latter is used in our experiments.

3. EXPERIMENTAL SETUP

In order to avoid the use of an ultra high precision machine tool in the development process of the alignment system and control algorithm, the air bearing of a roundness tester was used for all experiments. It has an equivalent precision as the air bearing of an ultra high precision machine but does not allow to control the angular position. Furthermore, the roundness tester represents another potential application of our alignment principle.
The friction force which is needed to hold the work piece on the support was caused only by the weight of the work piece.
As work piece we used a steel cylinder onto which an aluminum disc was attached. This disc was surface finished on an ultra high precision machine in order to obtain a high surface quality and a good roundness.

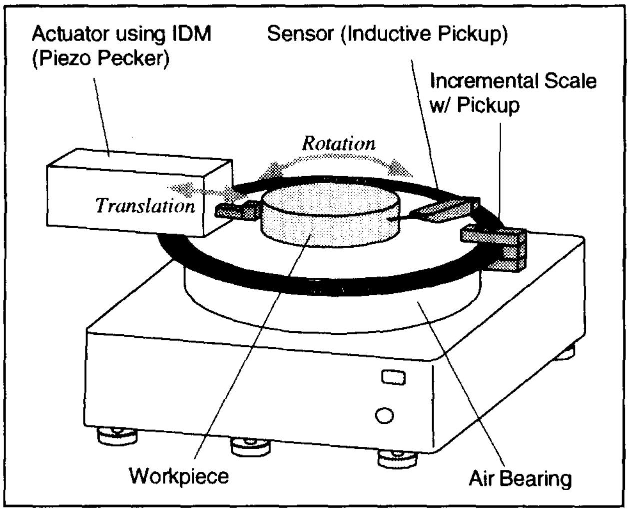

Fig.2 Experimental setup, overview

The surface roughness (about 40nm) and the unroundness (less than 50nm) can therefore be neglected for the positioning experiments. The diameter of this work piece was 60mm, height 50mm and the weight about 900g.
As IDM actuator a Piezo Pecker® (Chichibu-Onoda Co.) was used for the positioning and mounted beside the air bearing. The driving parameters for the piezo actuator are voltages between 60V and 100V and frequencies between 20Hz and 30Hz for a fast movement and between 5Hz and 10Hz for the high precision alignment of 10μm and better.
The position of the work piece on the rotating table as well as the step width were measured by means of an inductive pickup with a maximum resolution of 100nm. The angular position of the table was measured using an incremental scale with a resolution of 0.5 degrees (Fig. 2).

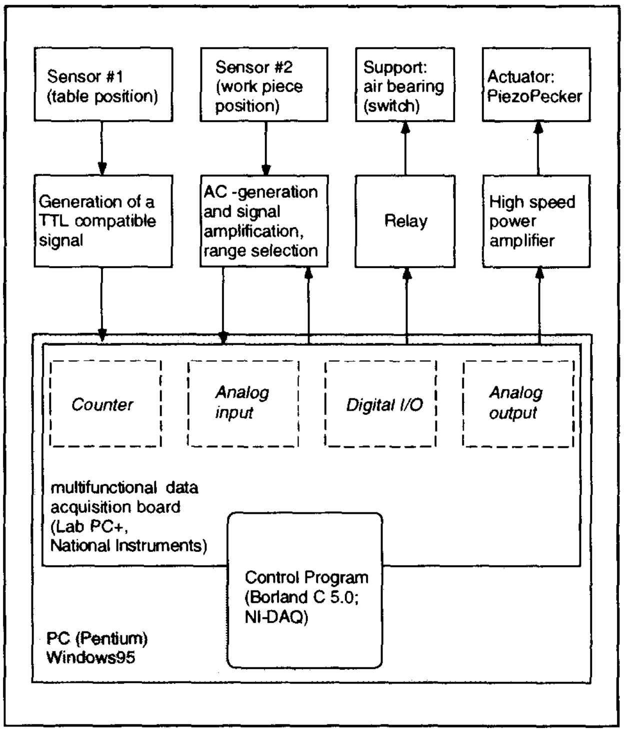

Fig.3 Experimental setup, block diagram

Measuring devices, the input of the high voltage amplifier for the Piezo Pecker and several switches were connected to a PC with a multi functional data acquisition board (National Instruments LabPC+) as shown in Fig.3.

4. POSITIONING ALGORITHM

An alignment takes place in five steps

(1) Switch the air bearing on and perform a rotation of 360 degrees while continuously acquiring data of the surface position
(2) Calculate the misalignment from the acquired data
(3) Continue rotation to the table position of the angle where a maximum displacement was found in step (1)
(4) Position the work piece using IDM while continuously measuring position and step size. Driving parameters are obtained from (2)

Afterwards the actuator must be moved backwards to release the work piece

(5) 2[nd] measurement of the inter-axial distance to determine the remaining misalignment

The interface for the inductive pickup allows to select 6 different measuring ranges. The largest range is 1.5 mm with a resolution of ± 50µm and the smallest range is ± 5µm with the highest possible resolution of 100nm.

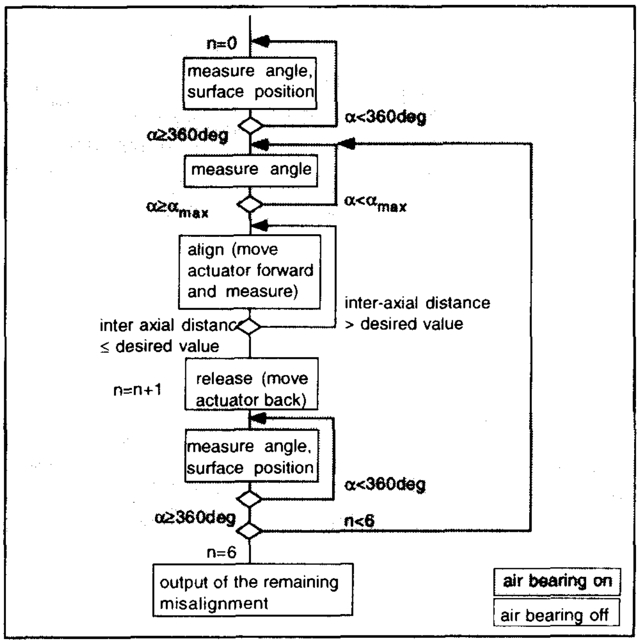

Fig.4 Operation of the control program (n ...number of ranges of the pickup interface, a ...table position, a_{max} ...angle at which the maximum displacement was found)

The work piece can in every range be aligned with a certain remaining misalignment which allows to switch to the next range. After the measurement of the remaining misalignment the next alignment cycle with the smaller range and higher precision follows.

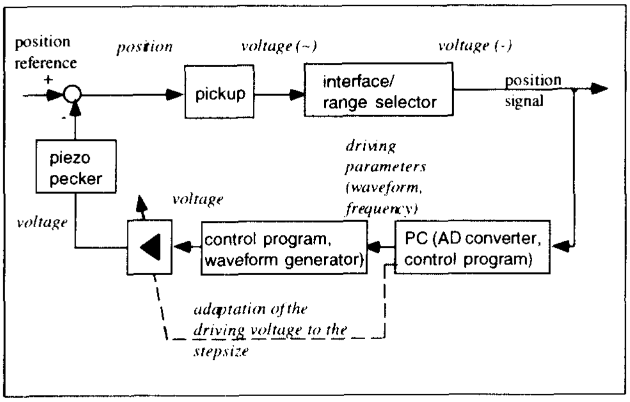

Fig.5 Control of the actuator (Piezo Pecker); the dashed line represents a possible adaptive control to compensate local variation of the friction force

Step (1) has therefore only to be performed in the 1[st] alignment cycle, the data obtained in the 5[th] step can always be used for the calculation of the misalignment in the next alignment cycle (See flow chart of the control program, Fig.4).

In step (4) of each cycle the driving parameters voltage, frequency and wave form for the actuator were controlled according to Fig.5.

While positioning, the work piece position was measured after each impact, compared to the previous position to obtain the step size and also compared to the desired position.

The driving parameters were updated as necessary or the alignment was stopped if the position was in a certain predefined range.

5. RESULTS

The total time to align a work piece which was manually positioned before can now always be less than 3 minutes. An usual value for the misalignment after manual positioning is 1mm.

The duration of the entire alignment procedure as mentioned above was in some cases only about 90 seconds depending on the inter-axial distance between the work piece and the rotating table.

It was mostly possible to decrease the number of alignment cycles from 6 to 4 or 3 because the inter-axial distance of work piece and table was small enough to leave out every second alignment cycle.

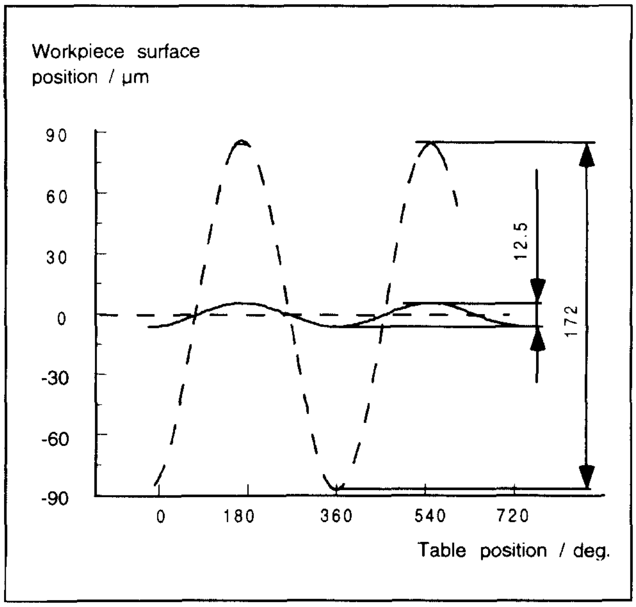

Fig 6 Surface position as a function of the table position before alignment (dashed) and after the alignment.

Fig.6 shows a plot of the surface position measured at the rotating table before an alignment and after the alignment The inter - axial distance was decreased by about 90 %. The range of the pickup interface was switched to ±150µm for this example.

It can vary between several 100nm and several micron. One alignment step allows to decrease the misalignment down to between 5% and 10%. Therefore it was possible to leave out every second measuring range. Fig.7 shows an example of the work piece positioning.

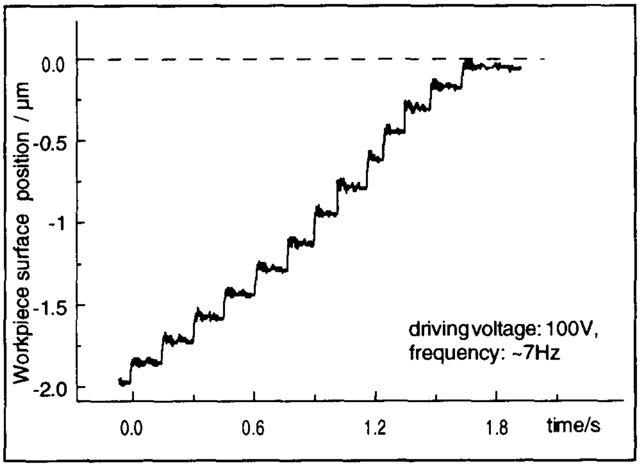

Fig 7. Surface position during the alignment

With every impact the static friction which keeps the object in its position changes to sliding friction. If, as in the particular case of our setup, the friction force is relatively weak, the motion of the pushed object does not always stop until the next impact takes place.

The movement of the work piece becomes uneven (Fig 8), the work piece does not move with every stroke of the Piezo Pecker because an impact between main body of the Piezo Pecker and the work piece does not always take place.

The smallest step size used for the positioning was less than 0.2µm. We succeeded in the alignment with a precision of 0.25µm (Fig 9).

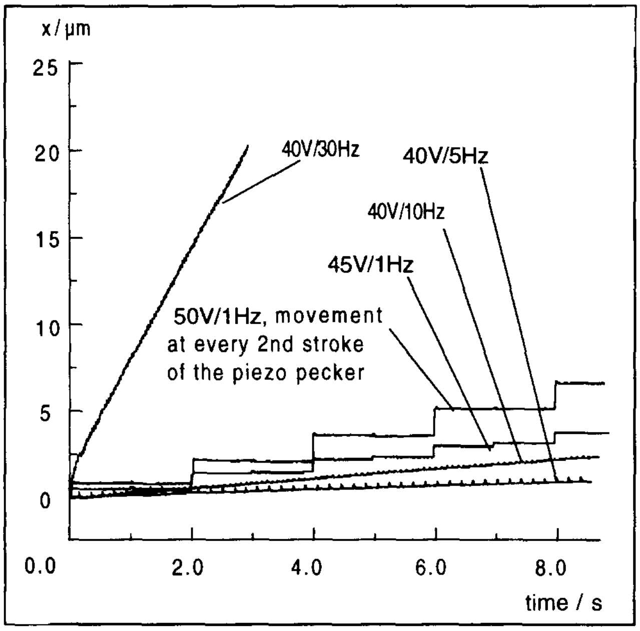

Fig. 8 Comparison between the movement of a pushed work piece at different driving parameters of the Piezo Pecker.

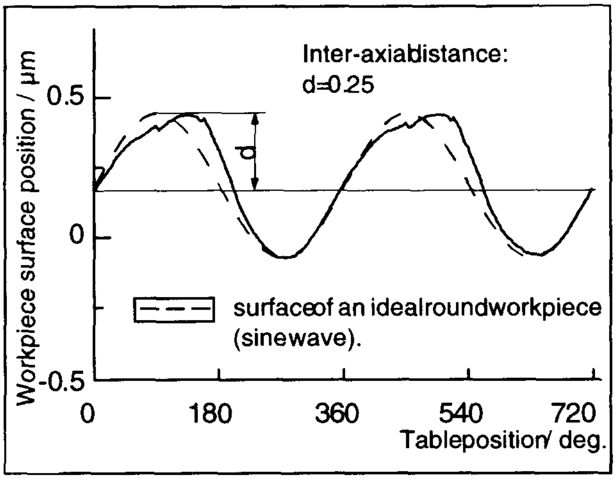

Fig 9 Surface position as a function of the table position.

6. CONCLUSION

The application of the IDM for the adjustment of work pieces on rotating supports is a promising way to decrease the duration of the alignment process as well as to increase the precision.

Although an adaptive control (adaptation of cycle time, driving wave form shape and amplitude) of the actuator movement was not yet implemented the positioning showed the desired result of a precision of less than 1µm within a comparatively short time.

Since only a PC with a DAQ-board, the piezo actuator and an amplifier for voltages between 60 and 100 V are needed, the presented solution could be a cost-effective way to solve similar alignment problems, e.g. in automated precision manufacturing systems.

REFERENCES

[HIG_87] T. Higuchi, Y. Hojjat, M. Watanabe:
» Micro Actuators using Recoil of an Ejected Mass «,
in IEEE Micro Robot and Teleoperators
Workshop Proceedings,
November 1987

[KAN_95] T.Kaneko, Y.Yamagata, T.Idogaki, T.Hattori, T.Higuchi:
» 3-Dimensional Specific Thickness Glass Diaphragm Lens for Dynamic Focusing «,
in IEICE Transactions, Vol E78-C,
February 1995

[YAM_95/1] Y. Yamagata, T. Higuchi:
» A Micropositioning Device for Precision Automatic Assembly using Impact Force of Piezoelectric Elements «,
in IEEE International Conference on Robotics and Automation Proceedings,
May 1995

[YAM_95/2] Y. Yamagata, T. Higuchi:
»Four Axis Ultra Precision Machine Tool and Fabrication of Micro Parts by Precision Cutting Technique«,
in 8th International Precision Engineering Seminar Proceedings,
May 1995