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AUTOMATIC COMPENSATION FOR ERRORS IN THE CNC DIVIDING TABLE

André Garcia Chiarello
Departamento de Mecânica, Escola Federal de Engenharia de Itajubá, CP 50, CEP 37500-903, Itajubá, MG. E-mail: andre@iem.efei.br.

Abstract. The computer numerically controlled (CNC) diving table is an equipment for generating angles with high accuracy and can be used as a programmable auxiliary axis of machine centers. This paper analyses the positioning errors of the CNC dividing table. The positioning errors are defined as the difference of actual and the programmed angular position. Firstly, the components of the dividing table and their design requirements were described. Afterwards, the mechanical components were manufactured and assembled and the positioning errors were analyzed. A low cost CNC was used for testing the dividing table accuracy. Two approaches for errors compensation were used: the mechanical approach and the software approach. The results showed that the positioning errors can be effectively minimized when both compensation techniques are used together.

Key words. Position errors, accuracy, feed drives.

1. INTRODUCTION

The dividing table is an equipment for dividing the circle in angles with high accuracy. The dividing table found wide application in industries, metrology rooms and laboratories. Basically, the dividing table is constructed with a rotating circular iron base coupled on a feed drive. The angular position can be measured using the angular scale fixed on the feed drive. There are two main types of feed drive: the mechanical and the automatic. The mechanical table uses a manually rotated gear reducer and the automatic table uses a programmable servo controlled feed drive. The table accuracy and resolution are function of the mechanical components tolerances.

The mechanical dividing table can be used as an auxiliary equipment of machine tools. However, the operator has to set the table angle manually before starting the machine operations. This aspect disables its uses on computer numerically controlled (CNC) machine tools or machine centers, because the CNC machine tools need dividing tables which are programmable like any other feed drive. This type of dividing table is known as CNC dividing table (Hoskins, 1986).

As an auxiliary programmable axis for CNC machine tools, the dividing table must show a good static and dynamic behavior. Hence, the design of mechanical parts must have this objective. The task of the mechanical system is to rotate the table in a specified angle and velocity with maximum accuracy. However, the problem of backlash is always present when the feed drive is based on reducer gears. The backlash is due to the mechanical clearances between mating teeth and acts as an unstable element into the control. Some backlash problems are analyzed in Ahn (1999) and Stein (1988, 1990). Therefore, the mechanical clearances of mating gears must be reduced to a minimum value or completely eliminated from feed drive. The analysis and design requirements of machine tool feed drives are well presented in Gross (1983), Srinivasan (1997) and Ramachandran (1998).

There are many techniques for addressing the problem of clearances in tooted gears and some are described in Trylinsk (1971). One well known approach of compensation for position errors is the use of split or dual gears, which has springs or screws between the halves. The mating gears are mounted preloaded by rotating the halves in opposite directions until all space between the teeth is set to a minimum value. Another approach is to use eccentric bearings supports. By rotating the eccentric bearing supports one can close mating gears.

The techniques described above use some form of mechanical compensation for gear clearances. Another approach for compensating the gear clearances is to use a CNC program. This approach is known as computer aided error compensation or automatic compensation. This method for compensating positions errors is based on the machine tool error map. The stationary or permanent errors described on the error map are used to program the CNC of the machine tool. The CNC program compensates each desired position in accordance with the corresponding value indicated in the error map.

It is well known that the stationary geometric errors can be accurately compensated by software (Ni, 1997; Lechniak et al., 1998); however, all machine tool also presents random errors. The random errors are associated with a great number of disturbing factors such as, unknown machine dynamics, control instabilities, non linear deformations of components and random disturbs from another machine tool. The compensation of random errors of a machine tool may be addressed by different approaches and is an interesting research subject (Chen, 1995).

A dividing table was designed to investigate the efficiency of automatic error compensation. Figure 1 shows the main parts of the dividing table feed drive. A low cost experimental CNC was used to control the dividing table. A 7.0 hp DC servomotor coupled to a gear reducer composes the feed drive of the table. The positioning sensor is a digital rotating encoder fixed to the servomotor shaft. The encoder resolution is 360/500 degrees and a DC servo amplifier with velocity control provides the electric power.

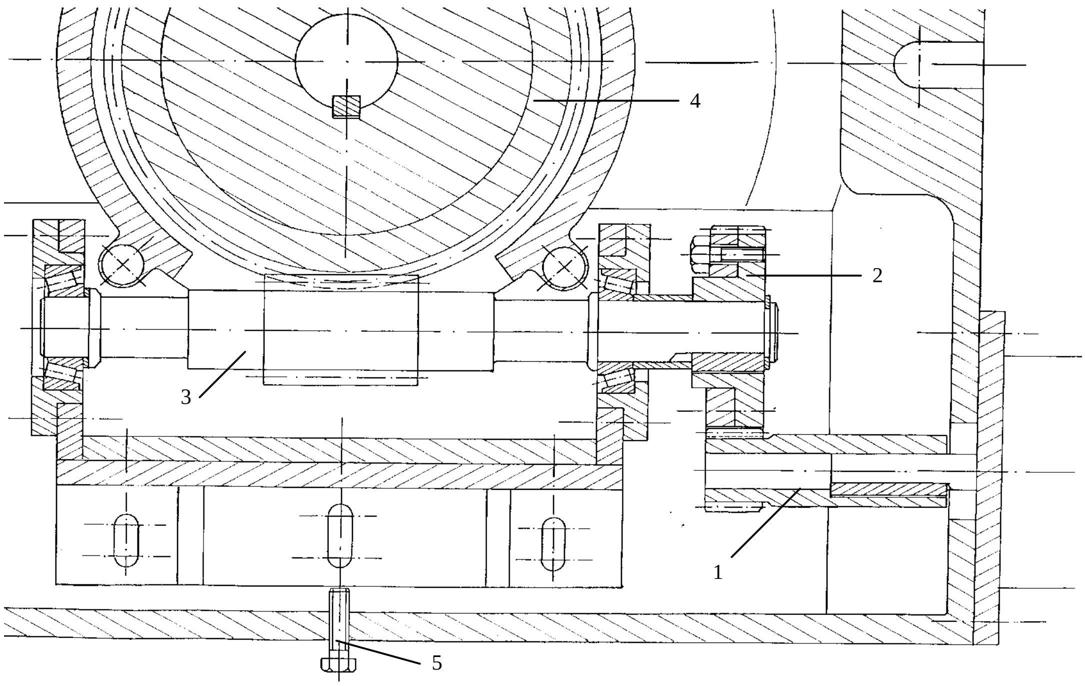

Figure 1. Feed drive of CNC dividing table. 1. Pinion, 2. Split gear,
3. Worm gear, 4. Worm wheel, 5. Adjusting bolt.

The table reducer is composed by two reduction stages: the first stage has a split gear and the second stage has a worn gear with clearance adjustment. The total reduction ratio is 172:1. The reducer objective is to provide a high torque in the table shaft and also guarantee positioning accuracy without control instability. The position resolution of the table shaft is 3.8 seconds of the arc. However, the final accuracy is a function of all mechanical components of the feed drive and also a function of the CNC accuracy.

The free play minimization between the pinion and the split gear is achieved rotating the two halves of the gear relative to each other. The minimum value of teeth clearance is, however, limited by mechanical efficiency. The worm gear also has an adjustment system for eliminating teeth clearance. The adjusting bolt showed in Fig.(1) can be rotated to move the worm gear shaft closer to worm wheel. The complete description of the dividing table assembly and the components dimensioning is given in Chiarello (1993).

2. POSITION CONTROL OF THE DIVIDING TABLE

The position control of the dividing table can be direct or indirect, depending on the location of the position sensor. Fig.(2) shows these two possibilities in the block diagram of the feed drive.

The indirect position control, the position of the table is recorded indirectly from the angular position of the screw or feed motor. The reversing errors behind the measuring location are active outside the position control loop. They appear as permanent position deviations and thus affect the positioning accuracy of parts to be machined. In this case, the mechanical parts of the feed drive must be manufactured and assembled carefully to eliminate all clearances and the residual position can be partially eliminated by compensating with the position control command value.

For direct position control, the measuring sensor is mounted directly on the dividing table shaft. The reversing error therefore act only within the position control loop and permanent position deviations do not occur. However, reversing error within the position control loop result in oscillations around the position controlled or inaccurate position approach.

As described previously, the positioning sensor of the dividing table is a digital rotating encoder fixed to the servomotor. This implies that all reversing errors appear outside of the control loop, avoiding oscillations around the position controlled.

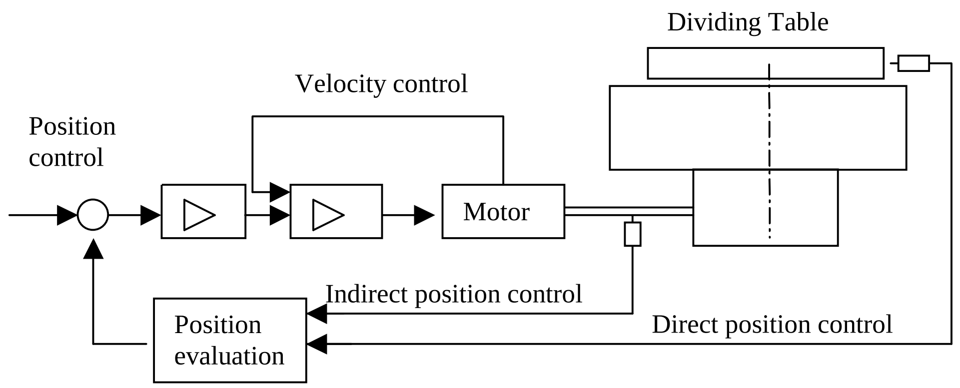

Figure 2. Position control loop with direct and indirect position control

Besides the type of control loop, the kind of measuring procedure is also important for position measuring system. There are absolute, incremental and cyclic measuring procedures. Absolute measuring procedures apply to both analog and digital working position systems. Each measuring value is assigned unequivocal signal value. Incremental procedures apply only for digital value detection. In this case there is no fixed zero point, but any point can be arbitrary declared zero by setting the position counting device accordingly.

The dividing table uses an incremental encoder as a measuring device and the advantage lies in the low hardware requirements for measuring value detection and simplicity.

3. POSITIONING ERRORS OF THE CNC DIVIDING TABLE

The table positioning errors were measured using the procedures defined in the VDI/DQG 3441-3445 (1977). To describe the position accuracy for any reference point, the following variables must be defined:

Stationary position errors, $\bar{x}_i$:

$$\bar{x}_i = \frac{\bar{x}_i \uparrow + \bar{x}_i \downarrow}{2} \tag{1}$$

$\bar{x}_i \uparrow$= mean value of position error for advance direction at observation point number i.

$\bar{x}_i \downarrow$= mean value of position error for return direction at observation point number i.

Reversion errors, r_i:

$$r_i = \left| \bar{x}_i \uparrow - \bar{x}_i \downarrow \right| \tag{2}$$

Standard deviation, s_i:

$$s_i \uparrow = \sqrt{\left[\frac{1}{n-1} \sum_{j=1}^{n} \left(x_{ji} \uparrow - \bar{x}_i \uparrow \right)^2 \right]}\ , s_i \downarrow = \sqrt{\left[\frac{1}{n-1} \sum_{j=1}^{n} \left(x_{ji} \downarrow - \bar{x}_i \downarrow \right)^2 \right]} \tag{3}$$

where, x_{ji} , $j = 1, \cdots, n$ is the individual positioning error value of each observation point i.

Mean value for standard deviation, $\bar{s}_i$:

$$\bar{s}_i = \frac{s_i \uparrow + s_i \downarrow}{2} \tag{4}$$

The dividing table was programmed to divide de circle in 20 parts. Each position point was measured sequentially in both advance and return direction. Each angular position was measured 5 times and the mean error value was calculated. The actual position value was measured using a mechanical dividing table, with accuracy of 1 second, which was concentrically fixed on the CNC table, as showed in Fig.(3).

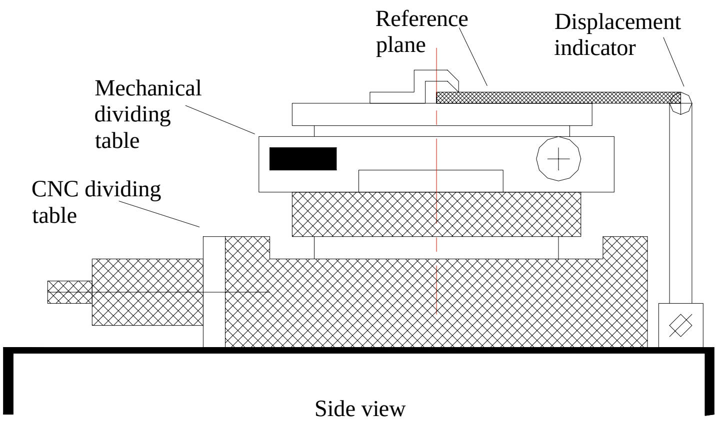

Figure 3. Set up for measuring positioning errors.

The linear difference between the actual and the programmed position was registered in the displacement indicator using a reference plane, which is fixed on the mechanical table. It is important to register that all position error was sequentially measured from zero degree to 360 degrees; hence, each angular position has the summation of all previous position errors.

The position error map of the CNC dividing table is showed in Fig.(4). The position error of the advance rotation differ from the position error of the return rotation. This difference represents the mean reversion error. The main cause of this error is the backlash of gear reducers, once backlash is always present when the table rotation is reversed.

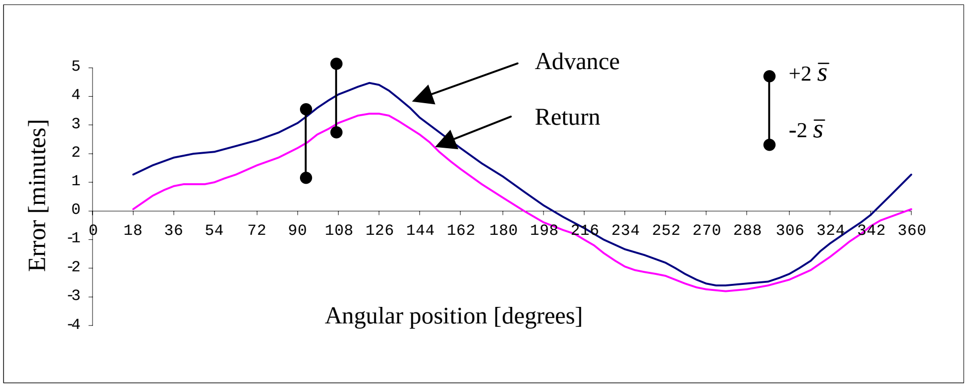

Figure 4. Position error map of the CNC dividing table.

4. AUTOMATIC COMPENSATION FOR POSITIONING ERRORS

The minimization of positioning errors is important for generating angles with high accuracy. The automatic compensation is an additional technique to the mechanical compensation technique. The approach used for automatic compensation of errors is based on the position error map showed in Fig.(4). A CNC program was constructed in a way that each desired angular position is adjusted by its respective error indicated in the error map.

The measured position errors using software compensation is less than 1 minute of the arc, as shown in Fig.(5). This result represents an improvement on positioning accuracy, once the maximum position error without automatic compensation is about 5 minutes of the arc, as showed in Fig.(4). Also, this result shows that the random errors, which were not modeled, introduces an error of approximately 2 minutes.

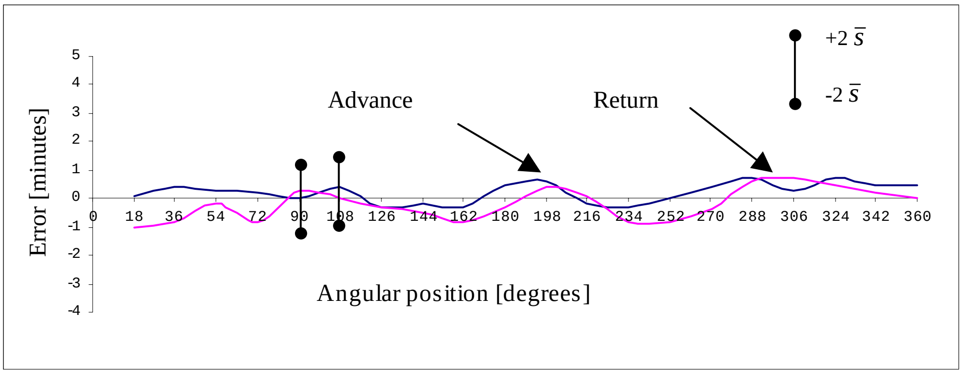

Figure 5. Dividing table positioning errors after automatic compensation.

The presence of random errors in the dividing table may be attributed to the great number of disturbing factors, for example, the control efficiency, the displacement sensor accuracy, the backlash in the feed drive and the elasticity of the mechanical components.

5. CONCLUSIONS

A computer numerically controlled dividing table was designed and tested using a simplified computer numerically controlled. The quality of the gears used in feed drive and its assembled tolerances is the most important issue to achieve high position accuracy. The mechanical technique used for eliminating feed drive clearances showed satisfactory results, however, the compromise with the mechanical efficiency must be observed.

As an additional technique for compensating position errors, the automatic approach was applied based on the position error map of the dividing table. Besides the improvement in the angular positioning accuracy, only the stationary errors can be effectively removed from the system. The compensation for random errors is an interesting subject and will be addressed in another work.

6. ACKNOWLEDGMENT

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