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Laser measuring device for lathe machine

Mr.M.Ranjith Kumar, Mrs. N.Sowjanya, Mrs. S.Ashlesha

Balaji Institute of Technology & Science

Abstract. The need for an efficient dimensional inspection of manufactured parts has lead to the development of different in process and on-machine measurement (OMM) techniques. Among these, the most utilized on a lathe consist on a touch trigger probe (TTP) similar to those used on coordinate measuring machines, but which accuracy on the machine is not sufficient for precision machining. Therefore, a different OMM technique is proposed in this work, which consists on a laser micrometer (LM) commonly used in-process for measurement of continues products. The behaviour of TTP and LM is analysed and discussed in terms of repeatability and reproducibility. A comparison is made between the two probes by measuring a cylindrical workpiece and checking the results with those obtained on a CMM.

Keywords: On-machine measurement, Laser Micrometer, Touch Trigger Probe, Turning.

INTRODUCTION AND OBJECTIVES

The current demand for high quality products has lead to the necessity of a total dimensional control of workpieces produced in order to avoid dimensional errors. Quality control of the manufactured parts has been traditionally performed with *offline* inspection methods and statistical sampling procedures after machining the part, when it is removed from the machine. It is commonly performed on Coordinate Measuring Machines (CMMs) under lab conditions. Although this procedure may be used when a high precision measurement is required, nevertheless, some defective workpieces should arise until the causes for these defects will be released. To overcome these disadvantages, other inspection techniques have been developed for prevention and compensation of errors in the processing stages of the workpiece. They are commonly based on a measuring sensor and a control system, by using optical, pneumatic, ultrasonic and electrical procedures for non-contact measurement,

and touch probes for contact measurement. Some of these techniques have been integrated *in-process*, performing the workpiece measurement while it is being processed with nointerruptions, whereas other techniques have been progressively integrated into machine tools leading to *on-machine* measuring procedures (OMM) [1] in which the workpiece is held on the machine and the machining process is stopped before starting the measurement. Both *in-process* and *OMM* techniques can be used to compensate the machine control for avoiding the feasible dimensional errors of the work piece.

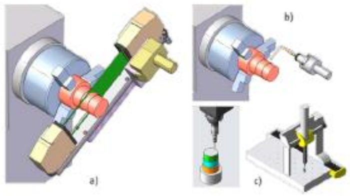

FIGURE 1. a) Laser Micrometer; b) Touch Trigger Probe; c) Coordinates Measuring Machine.

The contact devices used for part inspection on a lathe consist on touch-triggerprobes (TTPs) similar to those used on CMMs. Although TTPs may have enough repeatability (2 0.5————————————m) for part inspection according to manufacturers, the actual repeatability achieved once installed on a CNC lathe resulted about 2 3————————————m [2]. Another inconvenient of these probes consists on their dependence on geometric lathe misalignments and the X axis thermal drift when multiple points are inspected [3]. Another method of contact measurement was developed by Ostafiev et al. [4] who used the cutting tool itself as a contact probe. The measurement accuracy is about that of the TTPs, since it depends upon tool presetting procedure which was carried out by means of a tool presetting arm called Q-setter.

DESCRIPTION OF THE EQUIPMENT FOR OMM

Touch Trigger Probe

A TTP for workpiece measurement consist of a turret-mounted touch probe with a stylus ball tip. The working principle of a TTP is based on the emission of an electrical signal when physical contact with a probe is produced. This *trigger signal* is converted by an interface to be read by the CNC control instantaneously and translated into coordinates referred to the zero machine point. This method can be applied for measuring workpiece dimensions and also for direct or indirect compensation of tools. Accuracy of these measuring devices are influenced by different factors, such as the geometric errors of the machine tool, the own probe errors, detection of the actual probe-workpiece contact position, contact approach feedrate, thermal drift for both the turret leadscrew and the general machine structure. Different tests were conducted on a Jator TAJ-42 CNC lathe with 200x500 mm of working area with a Marposs T25 touch probe with a unidirectional repeatability of _ _ 0.5_m. Measurements done with this TTP have been compared with those obtained on a CMM DEA Global, which were considered as reference.

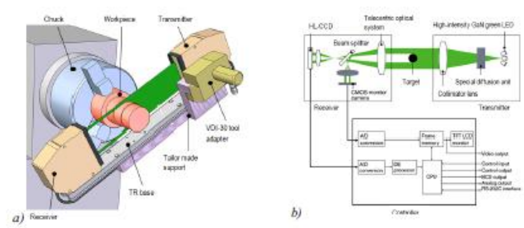

FIGURE 2. a) Configuration of the LM installed on the lathe; b) Principle diagram of the LM.

Laser Micrometer

The measuring device considered for non-contact measurements on the lathe was a high-speed, high-accuracy digital micrometer Keyence LS-7000, consisting on a LS- 7070 measuring head (transmitter and receiver) which was mounted on the tool-turret of the lathe through a tailor made adapter to VDI-30 turret system (Figure 2a). The principle of measurement of the LM is based on the emission of a high intensity light produced by a green led unit, which is transformed into uniform parallel light

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through the special diffusion unit and collimator lens and emitted to the target in the measuring range. The shadow image of the target appears on the high-speed linear CCD through the telecentric optical system. The output incident signal of the CCD is processed by a digital edge-detection (DE) processor in the controller and CPU. As a result, the dimensions of the target will be displayed and output (Figure 2b).

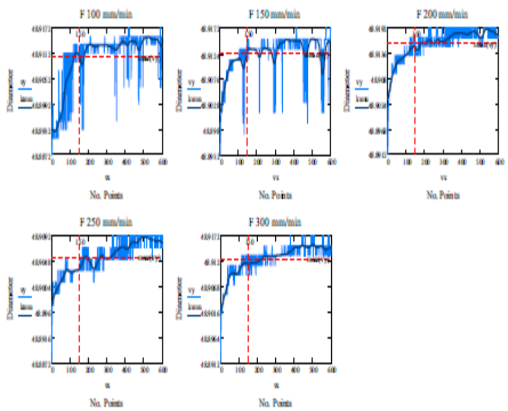

FIGURE 3. Evolution of measurements of a same point captured by the TTP under different values of feedrate (100, 150, 200, 250 and 300 mm/min).

CHARACTERIZATION OF THE OMM SYSTEMS

TTP Behaviour

Measurement of a workpiece profile by means of a TTP requires to inspect a high number of points distributed along the profile. Since this action requires a repetitive movement of the X axis for probe approaching, contact and repositioning, a previous study was performed in order to analyze the influence of thermal elongation of the X leadscrew under different feedrates (100, 150, 200, 250 and 300 mm/min). Figure 3 shows the evolution of the measurement acquired in front of the number of the repetition considered. It can be observed in all cases an increment of the measurement

A *Gaussian-Kernel-Method* (GKM) was applied for smoothing data and results were represented on Figure 3 as the *ksmu* curves, which show the evolution of the thermal drift better than the *vy* direct curves. Another outstanding consideration from Figure 3 is a higher dispersion of measurements for approach feedrates of 100 and 150 than for the rest cases. In order to quantify this parameter, a transformation of measured data was carried out by compensation of the thermal drift effect. Considering that the TTP tip presetting had been performed with no thermal elongation of the leadscrew, the compensation procedure considers that the first measurement is the most accurate and the rest have to be compensated accordingly. Therefore, the increment of the smoothed measurement values is used for this. It can be calculated as:

$$ksmu\_i = ksmu - \min(ksmu) \quad (1)$$

$$vy\_c = vy - ksmu\_i \quad (2)$$

where *vy* is the vector with the original measurement values. Figure 4 represents these thermally compensated values. Each picture includes a horizontal band of width ±2__ It can be observed that most part of compensated measured values lie inside this band. Moreover, Table 1 summarizes the calculated values for mean, standard deviation, 2_ and confidence level for each case. According to results in Table 1, the best values for the approach feedrate are 200, 250 or 300 mm/min, with a 2_ value of about 2.1-2.5 _m and a confidence level of about 95%. Considering this and the importance of productivity when multiple

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points have to be measured, the feedrate of 300 was chosen for the next analyses oriented to determine the reproducibility of measurement. For this, four additional tests were conducted for 1000 measurements of a same point on the workpiece with an approach feedrate of 300 mm/min and an approach distance of 5 mm. Presetting of the TTP tip was performed only before the first test. Each test was carried out just switched on the lathe, in the cool state. Ambient temperature was similar in all of the tests. Measured data were thermally compensated with the same procedure described before. The results in Table 2 show that both 2_ as the confidence level remain at a same level of quality than in the previous study for this approach feedrate, even although a greater number of repetitions (1000) have been performed. On the other hand, the mean value of measurements presents a significant dispersion with 2_ about 8 _m. This suggests that uncontrolled conditions on each test cause a lack of reproducibility. A way to fix this problem is to perform a TTP presetting before each of the tests, but this would not reflect the actual conditions in production, in which presetting is only carried out at the beginning of the batch.

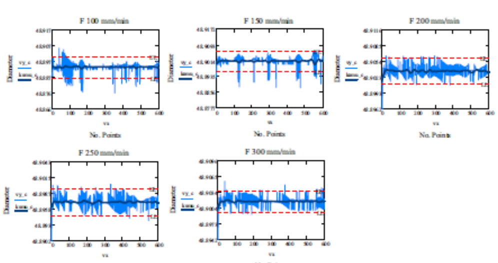

FIGURE 4. Thermal compensated measurements of a same point captured by the TTP under different values of feedrate (100, 150, 200, 250 and 300 mm/min)

TABLE 1. Statistical values for the thermal compensated measurements under different feedrates.

Parameter	100 mm/min	150 mm/min	200 mm/min	250 mm/min	300 mm/min
Mean	48.8930	48.9012	48.9035	48.8971	48.9016
2σ	0.0070	0.0053	0.0025	0.0023	0.0021
Confidence	92.2	94.0	95.8	97.5	95.5

TABLE 2. Statistical values for the compensated measurements for a feedrate of 300 mm/min.

Parameter	Test 1	Test 2	Test 3	Test 4	Mean	St. Dev.
Mean	48.9038	48.9104	48.9041	48.9110	48.9073	0.0039
2σ	0.0019	0.0021	0.0017	0.0020		
Confidence	96.0	96.3	95.1	95.3		

LM Behaviour

In order to analyze the LM behaviour, it was initially studied the repeatability when measuring a same diameter of the workpiece a great number of times with a frequency of 1 Hz. Six repetitions of that test were performed. Calibration of the LM was done initially. The first three tests were performed after switching on the LM, in a *cool state*. The other three tests were done after a long period of warming but with 30 minutes of gap between each other, in the *warm state*. Figure 5 shows the evolution of the measurements acquired by the LM in front of the elapsed time until the end of the measurement. It can be observed from the first three tests that the measures decrease progressively from the beginning until a certain moment in which they become stable, just when the laser reaches a steady temperature. Measures in the rest of tests were more stable from the beginning to the end since the LM temperature remained stationary. Therefore, in order to avoid the effect of laser stabilization, it is advisable to wait a minimum of 14 minutes before taking measurements with the LM. Taking this into account, only the three last tests were analyzed to determine repeatability and reproducibility. Results in Table 3 show that a low value of 2_=0.2 _m was achieved for a confidence level of about 95%. Therefore, the repeatability is of a higher order than in

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the case of the TTP. On the other hand, the mean values of measurements in the three tests are practically identical which in turn indicates that the LM becomes reliable and precise.

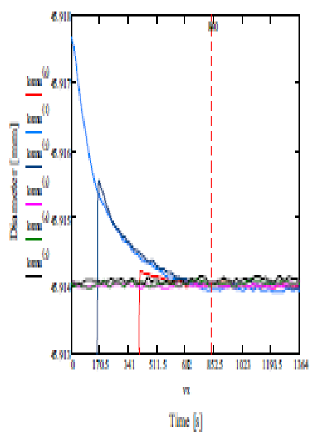

FIGURE 5. Evolution of a repetitive measurement with the laser micrometer for six tests

TABLE 3. Statistical values for the measurements taken by the LM.

Parameter	Test 3	Test 4	Test 5	Mean	St. Dev.
Mean	45.91403	45.91402	45.91407	45.91404	0.00003
2σ	0.00015	0.00019	0.00019		
Confidence	94.8	95.2	94.8		

CASE STUDY: MEASUREMENT WITH A TTP VS. LM VS. CMM

A cylindrical workpiece was turned on the lathe with a nominal diameter of 46.000 mm and a length of 145 mm. The workpiece diameter was measured starting from the end face towards the chuck in a length of 135 mm every milimeter.

Two trials were performed with the TTP with an approach feedrate of 300 mm/min and and 1500 mm/min of speed for displacement from one point to another. The measurements were thermally compensated. Similarly, other six trials were carried out with the LM after laser stabilization. Feedrates for movement between points were 120, 240 and 300 mm/min. Next, diameters of the cylinder were measured externally on a CMM using an approach feedrate of 240 mm/min. The resulting values were represented in Figure 6 for all the points along the workpiece length. It can be observed that different feedrates for the LM do not affect the repeatability of measurement. On the other hand, the superposition of the measurements obtained by each device shows a fine coincidence among all of them, especially between LM and CMM. Operational time of the three methods was compared each other. It was observed that the operational time of TTP and CMM with regard to the LM were 1.79 and 10.97 times greater, respectively.

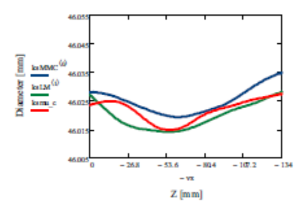

FIGURE 6. Results of measurements of a cylinder by different techniques: TTP, LM and CMM

CONCLUSIONS

This work compares two OMM techniques for workpieces on a CNC lathe: a touch trigger probe (TTP) and a laser micrometer (LM). The behavior of both instruments is analyzed. For the TTP, the most precise operation is achieved for an approach feedrate of 300 mm/min, meeting a repeatability of 2__ _m, but it showed a lack of reproducibility as well a necessity for compensation of the leadscrew thermal drift. The integration of the LM within the CNC lathe has allowed faster and more precise measurements than with the TTP. Minimum thermal influence was observed after a warming period of 14 minutes, and absolute measurements of diameters were taken, avoiding the influence of lathe misalignments and an accurate presetting of the LM. Good reproducibility was achieved, so that the LM becomes precise and reliable. Both OMM techniques were applied for measuring a cylindrical workpiece and the results compared each other and also with those obtained on a CMM. Quality was similar for LM and CMM but the TTP showed a worst behavior. Comparing the operational speed, the LM becomes the faster method followed by the TTP, whereas the CMM takes almost ten times more time. Consequently, the application on LM for OMM seems very useful for fast and precise profile measurements of workpieces.

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