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Traceable In-process Measurement (TIM) - Producing dimensional transfer artefacts for the assessment of workshop machine tool performance

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Abstract

Inspection of parts is traditionally carried, out once a manufacturing procedure has been completed, in an environmentally controlled metrology laboratory. Financial pressures, increases in production speed and automation have led to inspection moving out of the metrology laboratory to the production floor and traditional tactile sensing tools such as CMMs are being replaced by 3D optical scanners. The use of this novel technology allows for inspection to take place during manufacture rather than waiting for the part to be completed.

Unlike metrology laboratories, workshops tend to be particularly harsh environments where there is little control over important factors such as: temperature, humidity and lighting. With this in mind, NPL has designed and manufactured dimensional transfer artefacts to provide dimensional traceability from the metrology laboratory to the workshop. These artefacts include features that can be easily modelled mathematically, machined accurately and are representative of those typically produced on production lines.

Keywords:

Machine tools, metrology, workshop, CMM, dimensional, environment, 3D optical scanners

1. Introduction

The National Physical Laboratory (NPL) is a contributor to a European Metrology Research Programme (EMRP) project investigating the performance of traceable in-process measurements (TIM). This partnership involves several National Measurement Institutes (NMIs) within Europe, supported by industrial collaborators. While the roles of the NMIs vary, NPL has led the design and manufacture of these dimensional transfer artefacts.

Inspection of parts is typically carried out once a manufacturing procedure has been completed, in a metrology laboratory away from unfavourable production environments. Financial pressures, increases in production speed requirements and automation have led to inspection moving out of the metrology laboratory to the production floor and traditional tools such as Cartesian coordinate measuring machines (CMMs) are being replaced by 3D optical scanners. [1] The use of this novel technology allows for inspection to take place during manufacture, rather than waiting for the part to be completed, reducing waste.

2. Dimensional transfer artefacts

Dimensional metrology laboratories typically have tightly controlled environments with significant emphasis placed on controlling atmospheric conditions such as: temperature, humidity and cleanliness. Additional factors such as: lighting, air pressure, vibration and noise may also be monitored, regulated or mitigated against. Workshops tend to be the opposite; particularly harsh environments with little or no control over such factors. For example, the temperature in an uncontrolled factory workshop may well vary between 5 °C and 35 °C over the course of a year.

It is well understood that some of the above factors have an effect on dimensional measurements. A 1 °C change in temperature can cause a change of approximately 23 µm/m in aluminium [2], a significant change when aiming to achieve common tight tolerances, of the order ±0.01 mm. Similarly changes in the air pressure and humidity will affect its refractive index, influencing measurements carried out using optical equipment. Without the tightly controlled environment of the metrology laboratory, it may be almost impossible to identify which factors are likely to have an effect on measurements carried out in the workshop. For inspection to be successfully performed in this environment a link between the workshop and metrology laboratory needs to be established and this can be achieved through the use of dimensional transfer artefacts.

Measuring a thermally invariant dimensional transfer material standard in the metrology laboratory and then repeating this measurement in the workshop environment gives an indication of the performance of the workshop measurement system. [3] Using these two sets of measurements and the thermal correction capability of the machine tool, it may be possible to make a link to the metrology laboratory and allow for corrections, where necessary, to be made to the manufacturing process.

2.1 Designing dimensional transfer artefacts

When producing a dimensional transfer material standard to assist with making measurements outside of the metrology laboratory, it is important that the transfer standard contains features similar to those of the final part. The dimensional transfer material standard is therefore designed to be used as a comparative standard, allowing measurements of its known features to be compared to measurements of the features created on the manufactured part.

The dimensional transfer artefacts developed under the TIM project have been produced without a specific part in mind as these artefacts are designed to provide a proof of concept. Three NPL transfer artefacts have been produced, the first, (a) in figure 1, the “NPL machine tool circles standard”, is constructed of six cylinders, measuring from 65 mm to 275 mm in diameter and 15 mm tall, stacked upon each other. Rather than being stacked concentrically, these cylinders are arranged so that, when view from above, the centre lines lie on a helix, to remove rotational symmetry within the standard.

The second standard, (b) in figure 1, the “NPL machine tool squares standard”, is constructed of six squares stacked upon each other. These squares measure from 35 mm to 235 mm across and are again 15 mm tall. The centres of all the cuboids lie along a common axis in the centre of the standard and to remove rotational symmetry, each cuboid is rotated 15° from the previous cuboid, about the centre line.

The third standard, (c) in figure 1, the “NPL machine tool prismatic standard” differs from the other two in that all the features are placed on a single surface. It bears various prismatic shapes positioned in a grid formation on the surface of a 200 mm by 200 mm square. These prismatic shapes are machined in both positive and negative space and include: truncated cones, hemispheres and concentrically stacked cylinders. In the centre of the standard are two cylinders, again one in positive and one in negative space, with rounded ends.

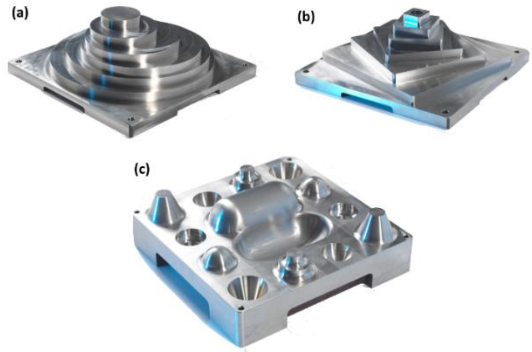

Figure 1. Photographs of the NPL dimensional transfer artefacts.

The NPL circles standard is designed to test the measurement system’s ability to measure the surface of cylinders and their central axis position. The squares artefact assesses the ability of the measurement systems to: measure linear dimensions, parallel and squareness measurements and also angle measurements between the sides of the various squares. The prismatic artefact has been designed to assess the performance of the measurement system when measuring typical 3D features that may be found on a manufactured part.

2.2 Manufacturing dimensional transfer artefacts

The dimensional transfer artefacts need to be manufactured from a material suitable for the harsh environment where they are to be used. They need to be resistant to wear when measured repeatedly with contact metrology tools, be strong enough to hold their form and resistant to changes in temperature. Invar, a nickel-iron alloy, was chosen as the material from which to create the artefacts because of its low thermal expansion coefficient, 0.13 µm/m [2], with physical properties comparable to steel. Unfortunately invar is susceptible to corrosion and rusting, leading to changes in the size and shape of the surface. Additionally, the reflective nature of a freshly machined finished surface does not lend itself to measurement using non-contact optical 3D scanners. To compensate for these two unfavourable properties NPL decided to develop a custom coating for the artefacts.

Following the testing of several coating materials and associated procedures, a final coating has been developed that not only protects the surface of the standard but also leaves it with a matt, diffuse, nominally Lambertian finish. This finish is created using a chemical coating process. Initially the invar surface is bead blasted to give a rough surface for the coating to bond to. Then two layers are placed onto the surface, the first a 2 µm layer of copper followed by a 2 µm layer of nickel. The resulting finish of the artefacts is left with a dull grey optical finish, similar to the appearance of concrete. This can be seen in figure 2.

Figure 2. Photograph of NPL machine tool circles artefact once coated.

3. Using dimensional transfer artefacts

Before its deployment in the workshop, the required transfer standard is accurately measured, using a tactile based high precision Cartesian CMM in a metrology laboratory environment. The NPL standard is then deployed to the workshop and placed next to the manufacturing machine tool. By combining the very low thermal expansion coefficient with the accurate measurement of the standard, it is possible to assess the ability of the metrology system of the manufacturing system, by comparing the measurement performed in the workshop with the metrology laboratory measurement. The user can now make informed decisions about the ability of their metrology equipment to perform accurate measurements in the workshop and whether it is possible to avoid taking the part to the metrology lab for inspection.

4. Conclusions

Increasingly, the inspection of parts is being performed before the manufacture process is complete and because of this measurements are taken outside of the metrology laboratory. With the unstable environmental conditions of a typical workshop it can be difficult to make accurate estimates of the uncertainty of any measurement performed. NPL has developed dimensional transfer artefacts to assist with the linking of shop floor measurements with those made in metrology laboratories. Use of these artefacts should increase measurement confidence, saving time and reducing material scrappage costs. 3D optical scanner measurement comparisons using the dimensional transfer artefacts are to be published in a future paper.

References

[1] M. R. Dury, “3D Optical Scanner Dimensional Verification Facility at the NPL’s ‘National FreeForm Centre,’” in *ASER Metrology and Machine Performance XI (LAMDAMAP 2015)*, 2015.

[2] “Tables of Physical & Chemical Constants, 2.3.5 Thermal Expansion,” Kaye & Laby Online, 2010. [Online]. Available: www.kayelaby.npl.co.uk.

[3] E. Trapet and A. Mart, “Self-centering probes with parallel kinematics to verify machine-tools,” *Precis. Eng.*, vol. 30, pp. 165–179, 2006.