# MEASUREMENT AND ANALYSIS OF SURFACE TABLE FLATNESS BY USING ELECTRONIC LEVEL ALONG WITH MOODY AND RECTANGULAR GRID METHODS

**Joab Sobreira de Andrade**
**Wagner Correia Peixoto**
**José Carlos de Lima Junior**
**João Bosco de Aquino Silva**
Universidade Federal da Paraíba,
Laboratório de Engenharia de Precisão (LEP)
Cidade Universitária - João Pessoa - PB – Brasil
CEP: 58051-900
engjoab@hotmail.com
wagnercp.engmecanica@gmail.com
limajr@ct.ufpb.br
jbosco@ct.ufpb.br

***Abstract.*** *Surface tables are extremely important in engineering due to the fact that they serve as a primary reference in both the measurement and inspection of workpieces. Such surfaces must be properly calibrated to provide high quality level in the measurement and inspection tests. Flatness is the metrological characteristic used to evaluate the accuracy level of the surface tables. There are several standards that deals with surface tables flatness and establish tolerance limit or accuracy degrees regarding to the surface tables dimensions. This study aims to measure and analyze the surface table flatness by using electronic level along with Moody and rectangular grid methods according to the ISO 8512 standard. An electronic level was used to measure the inclining level of the surface tables, using the well-known Moody and rectangular grid methods. The Optical Analysis Software calculated all flatness deviations, showing them in isometric and numeric charts. The calculated closure errors show the high quality in the measurement data acquisition because the values showed in all tests satisfy the electronic level manufacturer's recommendation, which means that the closure errors did not exceed 90 % of the maximum peak. Therefore, the results of evaluated surface tables are validated as regards metrological quality. The results point out that the surface tables belongs to the "0" accuracy degree according to the ISO 8512 standard. This classification is extremely important in the determination and analysis of uncertainty and of traceability since surface tables are primary reference to obtain tolerance measures and analysis of engineering workpieces.*

***Keywords:*** *flatness, surface table, electronic level, Moody method and rectangular grid.*

## 1. INTRODUCTION

Surface tables, or metrology tables, are extremely important in accuracy engineering since they are used mainly as surface reference in engineering components inspections as well as surface workplace for machine tools (Huang *et al*., 1993). They are usually manufactured in granite because of its peculiar characteristics as high wear, corrosion resistance, and low thermal expansion coefficient.

The evaluation of flatness deviation is essential to workpieces dimensional control and to qualify a surface as primary reference. The International Organization for Standardization - ISO 8512 (1990) - defines surface tables flatness as the minimal distance between two parallel planes in which all measured points on the surface table must be contained.

The ISO 12781 (2011) pattern specifies that the flatness error must be evaluated through two different methods: the Least Square Method (SLM) and minimal zone method (MZM). Through these methods, it is possible to determine the regression and reference plans to calculate the flatness errors. According to the same standard, flatness can be obtained by adding the higher absolute values from the calculated errors, also names as peak-to-valley.

The ISO 8512-2 (1990), which brings the specifications about the metrological tables of granite, specifies that the deviation or flatness error of these tables may not exceed the amounts shown in Tab. 1, due to its size and degree of accuracy.

Table 1. Tolerances according to the degree of accuracy for plates made of granite.

| Size of plate / mm | Tolerance on deviation from flatness overall for surface plates / µm | | | |
|---|---|---|---|---|
| | Grade 0 | Grade 1 | Grade 2 | Grade 3 |
| 160 × 100 | 3 | 6 | 12 | 25 |
| 250 × 160 | 3,5 | 7 | 14 | 27 |
| 400 × 250 | 4 | 8 | 16 | 32 |
| 630 × 400 | 5 | 10 | 20 | 39 |
| 1000 × 630 | 6 | 12 | 24 | 49 |
| 1600 × 1000 | 8 | 16 | 33 | 66 |
| 2000 × 1000 | 9,5 | 19 | 38 | 75 |
| 2500 × 1600 | 11,5 | 23 | 46 | 92 |
| 250 × 250 | 3,5 | 7 | 15 | 30 |
| 400 × 400 | 4,5 | 9 | 17 | 34 |
| 630 × 630 | 5 | 10 | 21 | 42 |
| 1000 × 1000 | 7 | 14 | 28 | 56 |

Several techniques have been proposed to measure surface tables flatness due to their dimensions and quality (Hume, 1963). To small dimensions surfaces like standard blocks and optical mirrors, the flatness deviation can be measured by interferometry, autocolimators or electronic levels (Masina and Kruger, 2014).

To perform the calibration of surface tables, Zahwi *et al*. (2013) used autocolimators, lazer system and coordinate measuring machine (CMM). To measure surface table flatness is required to trace measuring lines on it. The largely used tracing methods are the ones called Moody (1955) and rectangular grid.

In this paper, two distinct surface tables flatness were determined by using an electronic level and both the Moody and rectangular grid methods. The aim to use both methods was to perform an analytical comparison, pointing out their main characteristics.

The Optical Analysis Software program developed by Taylor Hobson Ltda. was used to collect measurement data and flatness results.

The main objective of this study is to calibrate two surface tables, determining their flatness values and, consequently, the accuracy degrees of each table according to the standards set by ISO 8512-2 (1990).

## 2. MATERIALS AND METHODS

### 2.1 Moody method

This method was proposed by Moody (1955) to calibrate round, square and rectangular surface tables. It is largely accepted worldwide since it permits a fast calibration. Also known as “Union Jack Method”, this method consists of tracing eight measuring lines on the surface table, according to Fig. 1. Each line is divided into several measuring stations whose base length must be previously defined. During the measurements the stations of diagonal lines, the base length must be properly altered so that the extreme and central points in which the diagonal lines cross coincide with the same points in which the perpendicular lines cross between them (Renishaw, 2001).

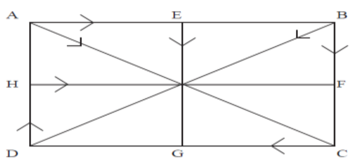


Figure 1. Union Jack pattern.

The Moody method is highly criticized because of its low points density presented in the data collection. It becomes even more critical when the surface tables dimension become bigger (Lakota and Görög, 2011).

### 2.2 The rectangular grid method

The main characteristic of the rectangular grid method is the presence of a high points density along the orthogonal directions. Despite the points density are not completed, it is possible to evaluate the harmonic content in both perpendicular directions. Therefore, this method is recommended as a sampling strategy to the overall flatness characteristics evaluation. This strategy consists of tracing several straightness profile, similarly separated, in two orthogonal directions to fit the purpose of forming a rectangular grid according to the example in Fig. 2 (Lakota and Görög, 2011). All in all, the rectangular grid permits to take any number of lines into two orthogonal directions, covering with high points density the surface table.

Figure 2. Grid pattern.

The disadvantage of this method in relation to the one developed by Moody is that it requires more time to collect data due to its higher quantity of measuring points and consequently higher computing process time to obtain flatness results.

### 2.3 Surface tables

Two surface tables made of granite, denominated as Surface Table 1 and Surface Table 2 in this study, being 1000 mm long, 630 mm wide and 155 mm thick, were used to evaluate flatness. Both tables serve as primary reference. Therefore, they need to be properly calibrated and their accuracy degrees need to be known.

### 2.4 Eletronic level - Talyvel 5

The electronic level is a device able to measure inclination in surfaces in relation to a determined reference plane. Different from laser measuring systems and autocolimators, the electronic level presents its own reference horizontal plane, what is an advantage since it enables highly accurate plane calculation (Runje *et al*., 2013). It is one of the most used measuring systems to perform flatness measurement in surface tables. Some other advantages of this device are its low cost, easy handling and its easy and fast way to obtain results (Gusel *et al*., 2000).

An electronic level, named Talyvel 5, was used to measure inclination on two surface tables. Talyvel 5 is an electronic system used to accurately detect the position of a pendulum in relation to its external casing. It is an easy-to-use device and does not demand a skillful operator to obtain repeatable and accurate results. Talyvel 5 is composed of two units: the level and the display units. The former is the level itself. It is the part which is placed on the surface that is about to be verified. It contains, apart from the pendulum, an electric transducer to detect the pendulum position. The latter contains the amplifier operated by the battery, a crystal liquid display which provides the values of the inclination reading within seconds (Taylor Hobson, 2005).

Some of the Talyvel 5 technical specifications are the following:

- Measuring rate: ± 600 seconds;
- Gradient: ± 3mm/meter ± 0,003 in/inch;
- Analogical output: 5 mV per arcsecond;
- System accuracy: 0,2 seconds ± 3 % of the value measured;
- Answer time: display stabilization time of 2 seconds;
- Operational temperature limit: -5 °C a 40 °C.

#### 2.4.1 Adjustable base

During the flatness measuring tests an adjustable base was used to pre-determine the basis length of the measuring lines. This length defines the intervals to be traced over each measuring line (generator), in other words, it is the dimension of each measuring station. With the adjustable base, it is possible to adjust the basis length of each measuring station within a value up to 200 mm, with the help of a graduate scale to measure flatness and straightness. It accommodates the level unit of the Talyvel 5 and the part which is assigned to be in contact with the component to be measured features an auto alignment system, designed with special shock-absorbing ball bearings. Inclination adjustment can be performed through a screw located in the upper part of the adjustable base, so it is possible to obtain a zero inclination, or near zero, in the first measuring station, to serve as reference to the other stations (Taylor Hobson, 2005).

**2.5 Optical Analysis Software**

The Optical Analysis Software was developed to Windows by Taylor Hobson's PRECISION company to work receiving measuring data in a direct way, using Talyvel 5, or in an indirect way, through manually inserting measured data. With this software, it is possible to perform both flatness and straightness analysis.

The software enables one to measure flatness deviation using both Moody (Union Jack) and rectangular grid measures. It features a straightforward menu, displaying an initial diagram of the surface to be measured along with the surface measuring lines (generators) and instructions about the insertion method of measuring data. After selecting the number of measuring steps, the program calculates and shows the form of each measuring line and the surface flatness, named peak-to-valley.

During the measurement procedure, the readings can be automatically inserted in the computer using the remote control of the Talyvel 5. Once the computer collects the values of the readings performed by the Talyvel 5, the values are displayed in arc seconds and after converted into micrometers (µm).

The results of the flatness measurement are displayed as an isometric diagram, as a data chart containing all flatness errors in each measuring point or as a certificate. In the latter representation, the flatness errors, in micrometers (µm), are displayed in each point or measuring station, forming the chosen tracing pattern, namely the Moody or the rectangular grid ones.

The Flatness Program uses the minimal zone method, according to ISO 8512 (1990) to determine flatness errors (Taylor Hobson, 2005). Thus, the software calculates the deviation of each point measured in relation to an ideal plane located in a minimal zone, in other words, between two parallel planes in which all measuring points are contained and whose the distance between the is as minimal as possible.

The Optical Analysis Software calculates one of the most important parameters in measuring flatness using both the Moody and the rectangular methods, namely error of closure, which is the maximum deviation that takes place between two measures in the same point or measuring station measured using different paths (Wyler, 2003). This parameter represents a measure of the accuracy and quality of the measurements. Taylor Hobson PRECISION recommends that the error of closure cannot exceed 90 % in either the peak-to-valley or the maximum peak values, thus assuring that the measurements are of good metrologic quality.

**2.6 Measuring procedure**

Firstly, the Surface Table 1 was cleaned up with an appropriate liquid and a soft piece cloth to remove any kind of dust or dirt that might influence in the results. By using a ruler and a soft chalk, the Moody pattern was traced to calculate flatness with an area of 400 mm x 800 mm. A soft piece of cloth was used again to remove tiny pieces of chalks, being careful to make the Moody lines to be visible.

Afterwards, the Talyvel 5 was mounted. It was necessary to wait some time so that the system stabilized and the thermal balance could be attained, which is about 20 °C.

The level unit of the Talyvel 5 was mounted on the adjustable base in which a base length of 100 mm was set over the six orthogonal lines. By measuring over the orthogonal lines, the base length must be properly altered. The Optical Analyss Software automatically provides this value, which must be used to adjustments using the adjustable base scale. By using this accessory it was possible to adjust the referential zero in the first station of the initial measuring line (generator).

Finally, the inclination measurements in each measuring line were performed, moving the unit group of adjustable level-base over the measuring lines and within equal spaces in relation to the base length. An extruded aluminum bar was used as a guide, assuring the straight route of the electronic level. All data were collected and automatically inserted in the Optical Analysis Software by using a remote control and the flatness result was obtained.

The rectangular grid profile now is traced on the Surface Table 1 using the same procedures for the first test. The same drawn area was used with the Union Jack method.

In the rectangular grid method the base length is always the same in all measuring lines (generators). It was set in 100 mm, thus, the rectangular grid was formed by 5 lines in one direction and nine perpendicular lines in another. By the end of the data collection, the Optical Analysis Software calculates and shows the flatness deviation results.

All the aforementioned procedure was similarly performed in the Surface Table 2.

The Figure 3 shows the setup used for the flatness tests on surface tables.

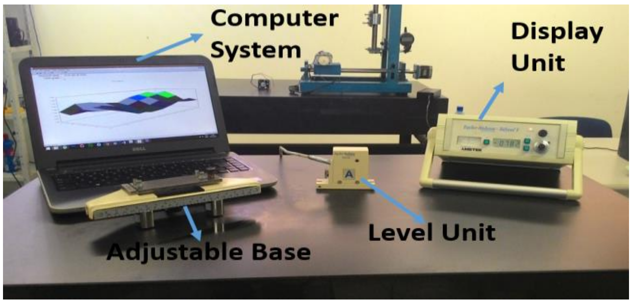


Figure 3. Setup of the measuring system.

## 3. RESULTS

The Optical Analysis Software presents the deviation measuring results through isometric graphic representation, data list and certificate. The Figure 4, Fig. 5, Fig. 6 and Fig. 7 below show the flatness results of the Surface Table 1 using the Moody and the rectangular grid methods generated by the Flatness Program.

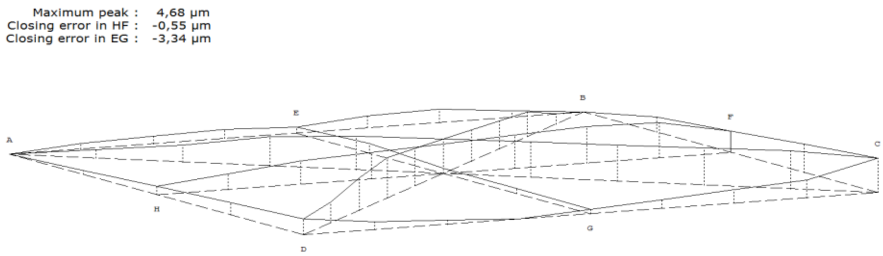


Figure 4. Union Jack isometric plot – Surface Table 1.

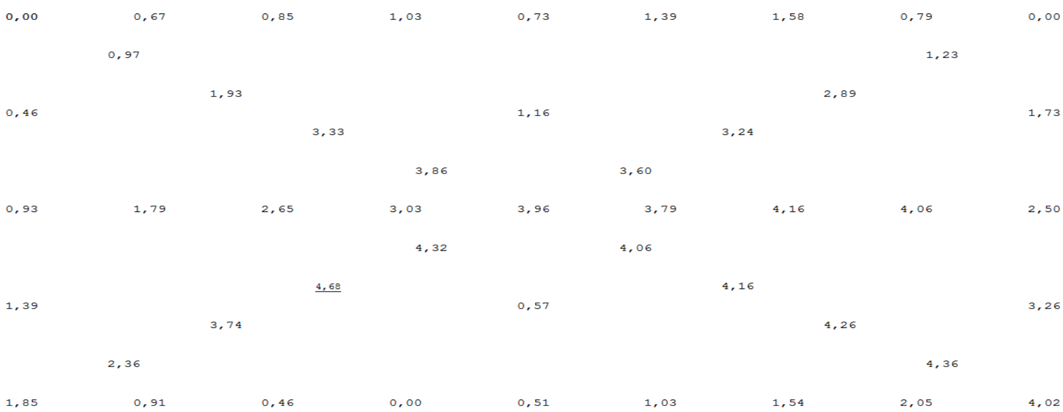


Figure 5. Union Jack certificate – Surface Table 1 (values in µm).

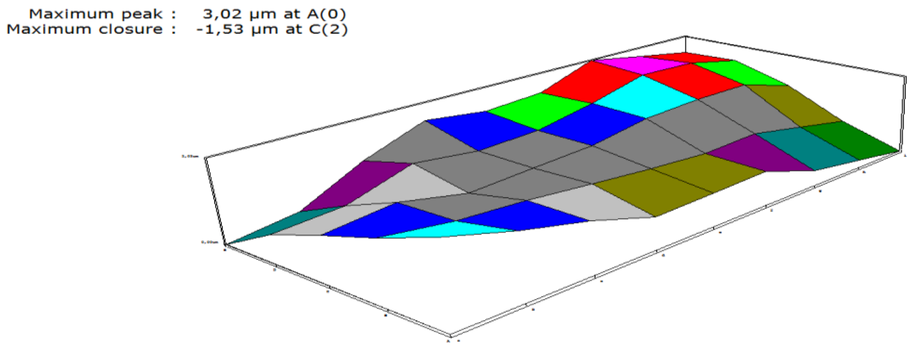


Figure 6. Grid isometric plot – Surface Table 1.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 0,00 | 0,37 | 1,52 | 2,38 | 2,11 | 2,26 | 3,02 | 2,66 | 2,32 |
| 1,04 | 1,22 | 1,99 | 1,74 | 1,87 | 2,30 | 2,86 | 2,81 | 2,38 |
| 1,69 | 1,98 | 1,53 | 1,70 | 1,83 | 2,21 | 2,35 | 2,36 | 1,75 |
| 2,31 | 2,02 | 1,90 | 1,70 | 1,54 | 1,39 | 1,48 | 1,09 | 0,71 |
| 3,02 | 2,36 | 1,87 | 1,17 | 1,23 | 1,29 | 0,60 | 0,30 | 0,00 |

Figure 7. Grid certificate – Surface Table 1 (values in µm).

The flatness value to Surface Table 1, using the Union Jack method, was 4,68 µm, presenting closing error of -0,55 µm in line HF and -3,34 µm in line EG. Using the rectangular grid method the maximum flatness error value obtained was 3,02 µm with closing error equal to 1,53 µm.

The results from Surface Table 2 are presented below on Fig. 8, Fig. 9, Fig. 10 and Fig. 11.

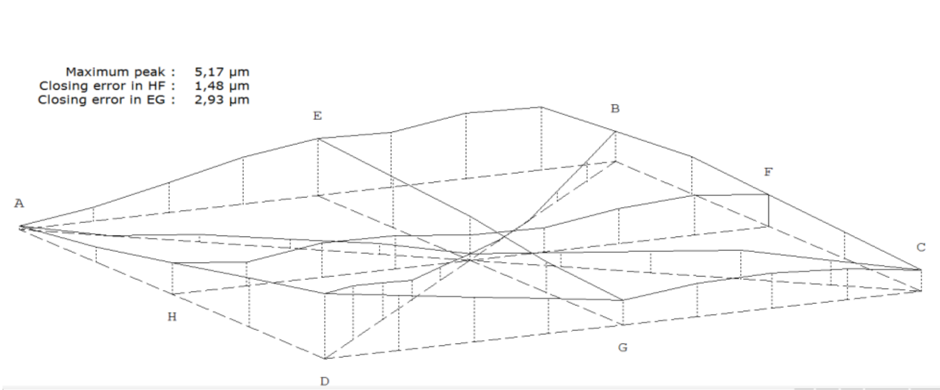


Figure 8. Union Jack isometric plot – Surface Table 2.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 0,30 | 1,11 | 2,41 | 3,70 | 4,51 | 4,36 | 5,17 | 5,01 | 2,43 |
| | 0,00 | | | | | | 1,62 | |
| | | 0,57 | | | | 0,81 | | |
| 1,15 | | | | 4,00 | | | | 2,97 |
| | | 0,71 | | | | 0,00 | | |
| | | | 0,84 | | 0,06 | | | |
| 2,49 | 1,89 | 2,74 | 2,63 | 0,55 | 1,91 | 2,76 | 3,13 | 2,53 |
| | | | 1,04 | | 1,12 | | | |
| | | 1,53 | | | | 1,69 | | |
| 3,83 | | | | 2,48 | | | | 2,10 |
| | | 2,89 | | | | 2,26 | | |
| | 4,25 | | | | | | 1,96 | |
| 5,17 | 4,37 | 3,57 | 2,76 | 1,96 | 2,62 | 2,78 | 2,47 | 1,67 |

Figure 9. Union Jack certificate – Surface Table 2 (values in µm).

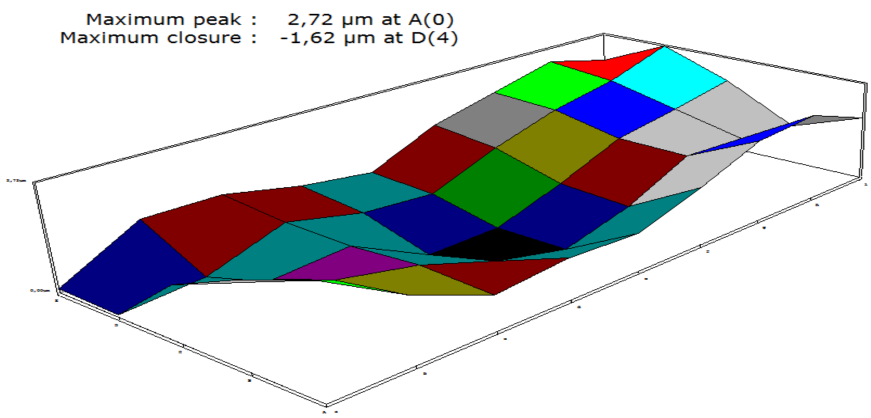


Figure 10. Grid isometric plot – Surface Table 2.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 0,11 | 1,20 | 1,19 | 0,82 | 0,61 | 1,41 | 1,86 | 2,31 | 1,91 |
| 0,06 | 0,26 | 0,98 | 0,57 | 0,49 | 1,20 | 1,75 | 2,12 | 2,72 |
| 1,41 | 0,75 | 0,93 | 0,00 | 0,04 | 0,66 | 1,36 | 1,69 | 2,04 |
| 2,11 | 1,38 | 1,02 | 0,39 | 0,00 | 0,51 | 1,32 | 1,25 | 1,08 |
| 2,72 | 1,63 | 0,88 | 1,05 | 0,99 | 1,52 | 2,18 | 2,34 | 1,74 |

Figure 11. Grid certificate – Surface Table 2 (values in µm).

The flatness value to Surface Table 2, using the Union Jack method, was 5,17 µm, having as closing error 1,48 µm in line HF and 2,93 µm in line EG. By using the rectangular grid method, the maximum flatness error value obtained was 2,72 µm, with closing error equal to -1,62 µm.

## 4. ANALYSIS AND DISCUSSION OF THE RESULTS

The calculated closing errors show high quality in the acquisition of measuring data since the values presented in all tests are in accordance with Taylor Hobson PRECISION, which means that the closing errors did not exceed 90 % of the maximum peak. Therefore, the flatness results are valid under the perspective of the metrologic quality.

To determine the accuracy degree of the surface tables in this study, the flatness deviation results were compared with the values showed on Tab. 1. It was found that all flatness deviation values point out that the Surface Tables 1 and 2 belongs to the accuracy degree “0” in accordance with the standard ISO 8512 (1990).

This result shows that, regardless the measuring lines tracing method being used, be it the Union Jack or the rectangular grid ones, the results converged, pointing to an equal accuracy degree. It is worth mentioning that the main advantage of the Moody method is the speed at which the method collects the data and resents the results. Having said that, when the speed at which the surface tables are calibrated is a key factor, it is recommended to use the Moody method instead of the rectangular grid one, mainly when dealing with tables with small dimensions.

However, when the surface table has bigger dimensions, the rectangular grid method is the one adequate, since it covers with higher density if points the measuring area, thus obtaining more accurate flatness results.

The differences in the flatness values obtained may be due to random errors related to the variation in the temperature where the research was carried out, mechanical vibration of the electronic level when moved, presence of tiny particles on the surface table, among other factors that directly influenced on the measurement uncertainty. Gusel *et* *al*. (2009) measured the uncertainty in flatness measurement of surface tables taking into consideration some of the aforementioned factors.

## 5. CONCLUSION

The surfaces tables 1 and 2 were properly calibrated through the determination of their flatness deviation by using an electronic level as a measuring system. With this equipment, it was possible to determine the flatness measurements in a fast and efficient way.

The well-known Moody and rectangular grid profiles were used to determine the flatness of the surface tables, emphasizing their peculiarities.

All flatness results point out that both surface tables belongs to the accuracy degree “0” according to standard ISO 8512 (1990). This classification is utterly important in the analysis and determination of uncertainty and traceability since the surface tables serve as primary reference to obtain measurements and tolerance analysis in engineering workpieces.

## 6. REFERENCES

Gusel, A., Acko, B. and Sostar, A., 2000. “Assuring the traceability of electronic levels for Calibration of granite surface plates”. In: *Proceedings XVI IMEKO World Congress - IMEKO2000*. Austrian Society for Measurement and Automation. Vienna, Austria.

Huang, S.T., Fan K.C. and Wu, J.H., 1993. “A new minimum zone method for evaluating flatness errors”. *Precision Engineering*. Vol. 15, p. 25–32.

Hume, K.J., 1963. *Engineering Metrology*, Macdonald & Co, London, 2nd edition.1963.

ISO 8512-1, 1990. Surface plates, Part 1: Cast iron.

ISO 8512-2, 1990. Surface plates, Part 2: Granite.

ISO 12781, 2011. Geometrical product specifications (GPS) - Flatness – Parte 1: Vocabulary and parameters of flatness.

Lakota, S. and Görög, A., 2011. “Flatness measurement by multi-point methods and by scanning methods”. *Ad Alta: Journal of Interdisciplinary Research*, Vol. 1, p. 124- 127.

Masina, P.P. and Kruger, O.A., 2014. “Flatness Measurements on a Granite Surface Table by Interferometry and by Electronic Level Using the Moody Method”. In *Test and measurement Conference.* National Metrology Institute of South Africa, South Africa.

Mood, J.C, 1955. “How to calibrate surface plates in the plant”. The Tool Engineer.

RENISHAW, 2001. “Flatness measurement user guide” <http://resources.renishaw.com /en/details/white-paper-interferometric-angle-measurement-and-the-hardware-options-available-from-renishaw--56681>.

Runje, B., Marković, M., Lisjak, D., Medić, S. and Kondić, D., 2013. “Integrated procedure for flatness measurements of technical surfaces”. *Tehnički vjesnik*, Vol. 20, p. 113-116.

Taylor Hobson, 2005. Talyvel 5, Operator’s Handbook. Spectrum Metrology Ltd.

WYLER, 2003. “Details to the alignment method according to ISO1101 and to the closure error correction according to Philips when using the wyler flatness measurement software levelsoft pro”.<http://www.wylerag.com>.

Zahwi, S.Z., Amer, M.A., Abdou, M.A. and Elmelegy, A.M., 2013. *“On the calibration of surface plates”.* Measurement, Vol. 46, p. 1019-1028.

## 7. RESPONSIBILITY NOTICE

The authors are the only responsible for the printed material included in this paper.