Calibration of machine tools by means of laser measuring systems

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***Abstract*—The need for very precise measurements has emerged with evolution of automatic and CNC machine tools. Precision and accuracy are amongst main requests on modern machine tools. To define and know this characteristic of machine tools standard measuring procedures have been used for many years. Yet, others more advanced approaches and equipments, like laser measuring systems, are also available for measuring machine parameters like straightness of movements, repeatability, surfaces flatness, parallelism etc. This paper shows comparison of measuring results and measuring procedure between two different laser measuring systems, Damalini D525 and Renishaw ML10. Measurements are performed on DMU monoBlock60, CNC universal milling machine. Same type of measurements, straightness measurement of main shaft movement in Y direction, is performed simultaneously by means of both of the laser systems. Results presented in this paper shows that there are differences in between measuring results as well as in between measuring procedures for selected lasers. Hence, the correct choice of measuring device in that sense can save time and decrease costs of machine maintenance.**

***Index Terms*—Laser, laser application, measurements**

I. INTRODUCTION

Measurement is inevitable part of any machining process. The accuracy requirements of machined products are constantly increasing. The accuracy level of machined products is directly related to the performance of machine tools used in production line [1]. Competitive products and an effective production line in modern enterprises demand constant checking of machine tools performance [1], [2]. Thus, the geometrical accuracy of CNC machine tools can be the basis for rating CNC machine tools according to their performance [1],[3],[5]. One of most important measurement is machine tool calibration [4]. A quick accuracy test of a CNC machine tool can be performed with the Ballbar QC10 devices [3],[8],[13],[14] and calibration and parameter correction on the CNC controller can be done with a test-results analysis from the very accurate ML10 laser device [1],[4],[6],[9],[10]. One of the methods for machine tool calibration is calibration using laser measuring systems. Lasers made possible to involve new measurement technique for measuring different physical properties, but their main application is in distance measuring. Accurate measurement using laser beam can be done in three different ways (depending upon dimensions of the object and its distance):

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a) Interferometer method,
b) Telemetric with modulated beams,
c) Optical radar.

A. Principle of laser

Laser is a beam of concentrated light which possesses enormous amount of energy. The word LASER is an acronym which stands for: **L**aser **A**mplification by the **S**timulated **E**mission of **R**adiation, which means that energy is coming from stimulated source of light. Nowadays, two major types of lasers are being produced i.e. CO_2 and Nd:YAG-Neodymium-doped, Yttrium Aluminum Garnet. Basic facts of laser light say that it is: (a) coherent (all photons of the laser beam are in the phase with each other), (b) directional (all photons are parallel and directed), and (c) monochromatic (all photons are the same energy so the laser beam color depends upon energy source which is used for stimulation of atoms).

CO_2 lasers belong to a group of strong lasers (400 to 1500 W) and there are used mainly for cutting and profiling. Carbon steel plate 25 mm tick can be cut using these lasers. Figure 1 shows principle of CO_2 laser.

Main advantage of lasers is its capability of transporting through optical cables, which is extremely important with laser welding using robots, where the laser head is placed in a robotic arm to be able to weld complex elements.

Nd:YAG works on a same principle as CO_2 laser, and they belong to a group of low power lasers. They are adequate for drilling of holes with small diameter (2-3 mm to 6 times diameter of the hole) and for engraving.

Low power lasers are used for laser measurements because laser destructive power is not adequate in measurements.

Laser measurement is based on a principle of optical interferometry of basic beam and the return beam which is carrying certain information. The return beam is usually reflected from a mirror which is placed on an observed object.

Main problem during laser measurements is laser beam stability. Since laser beam wave length is used as a gauge in measuring, the influence of the environmental conditions (temperature, humidity) must be effectively controlled.

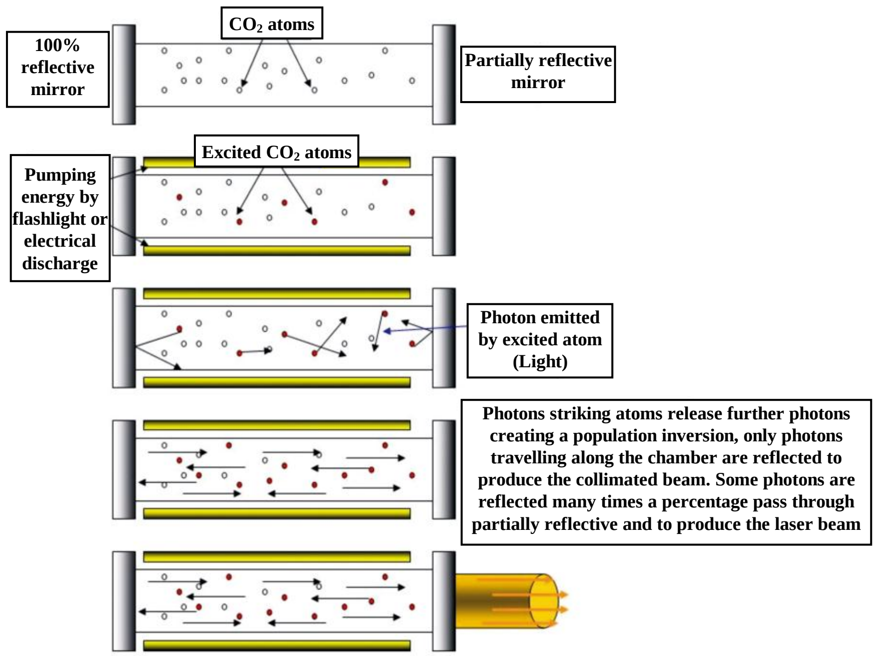

Fig.1. Principle of CO_2 laser

B. Basic machine tool measurements using laser

Following measurements can be performed using lasers (Fig.2): (a) linear positioning accuracy and repeatability of axis, (b) straightness of axis, (c) squareness between axis, (d) flatness of surface, (e) rotary axis angular positioning, (f) angular pitch of axis, and (g) dynamic characteristics of machine tool.

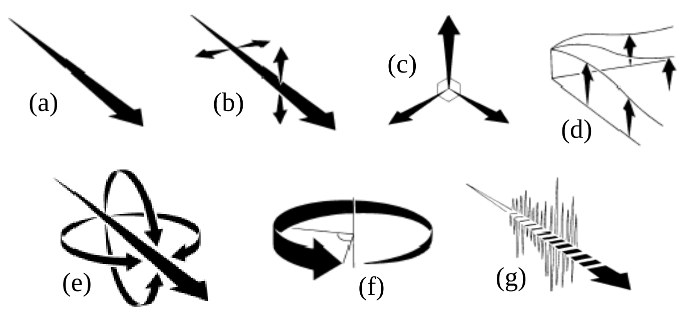

Fig. 2. Basic measurements usig laser

In the practical example of determining straightness of an axis following laser calibrating systems have been used RENISHAW ML10 (Interferometer), and DAMALINI D525 (PSC – Position Sensitive Device).

Laser systems used in a practical example enable complete calibration of a machine tool, being able to measure great number of geometric and dynamic properties of a machine tool. Used systems are based on a two different principles of detection of laser beam which caries certain information. RENISHAW laser system uses principle of interferometry and DAMALINI laser system uses PSD detector for laser beam detection.

II. Measuring Principles

A. Interferometry (Ranishaw laser system)

Principle of interferometry is discovered in 1880 by Albert Michelson. Michelson's interferometer comprises the source of monochromatic light, semitransparent mirror and two mirrors as shown in Fig. 3.

On a semitransparent mirror light beam is split in two parts. One part goes towards movable mirror and the second part is reflected under 90° angle towards fixed mirror. Mirrors are placed in such a way so that recombined light beam goes towards observer. If both mirrors are on the same distance from semitransparent mirror then both beams reflected towards observer will bi in phase which will result in amplification of the light intensity. If the movable mirror is placed ¼ wavelengths away from fixed mirror, then the return beam is 180° out from the phase of base light beam and that results in so called "destructive interferometry" which produces dark on a screen.

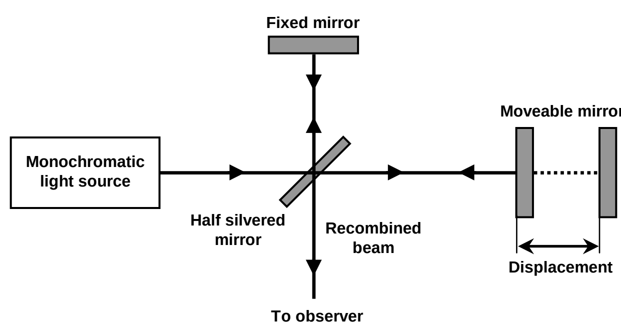

Fig. 3. Michelson's interferometer

B. PSD detectors (Damalini laser system)

PDS detector is a silicon film sensitive to light. In comparison to digital camera in which the resolution is defined with the camera design these detectors are analog and can have almost unlimited resolution (Fig. 4). When laser beam hits silicon film electrical current begin to flow from point of impact towards electrode. The intensity of current is proportional to distances of an impact point from each electrode. Based on intensity of current exact location of laser beam is calculated. This principle enables resolution literally 1:1000000.

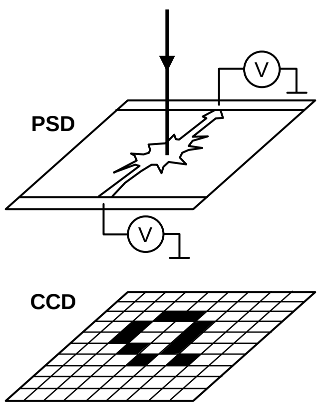

Fig. 4. Comparison of PSD detector to CCD chip of digital camera

III. Practical Example

A. Definition of straightness measurement

Straightness measurement shows misalignment of an axis. This measurement identifies misalignment of a given axis from ideal one, or from reference guide way of a given machine element (Fig. 5). This misalignment can come from wear of guide ways, damaged or poor machine foundations etc. This deviation of straightness has direct impact on a tool positioning accuracy.

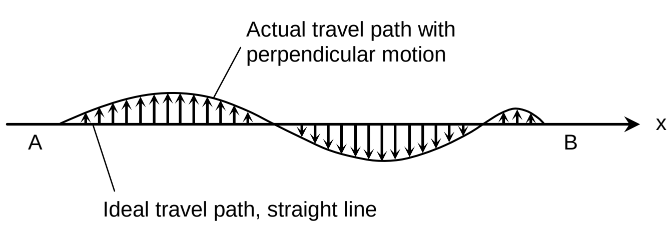

Fig. 5. Definition of straightness

B. Measurements performed using Renishaw laser system

Renishaw laser system measures accuracy of straightness and repeatability of machine movement by measuring deviation of target points from reference axis.

Using RENISHAW laser 10 system straightness of main shaft movement of CNC mill DM 60 monoBLOCK in direction of Y axis is performed. Measurement is performed on a length of 490 mm from outmost position towards machine bed. According to machine producers specification this deviation should be less then 0.02 mm on 300 mm length.

Laser source on this laser system is positioned on a tripod outside of a machine, while interferometer is positioned on a movable part and mirror is positioned on a stationary part of a given machine. Deviation of target points from reference axis, which is positioned between laser source and mirror on a stationary part of a machine, is measured. Typical system setup for straightness measurement using RENISHAW laser system is shown in Fig. 6 and Fig. 7.

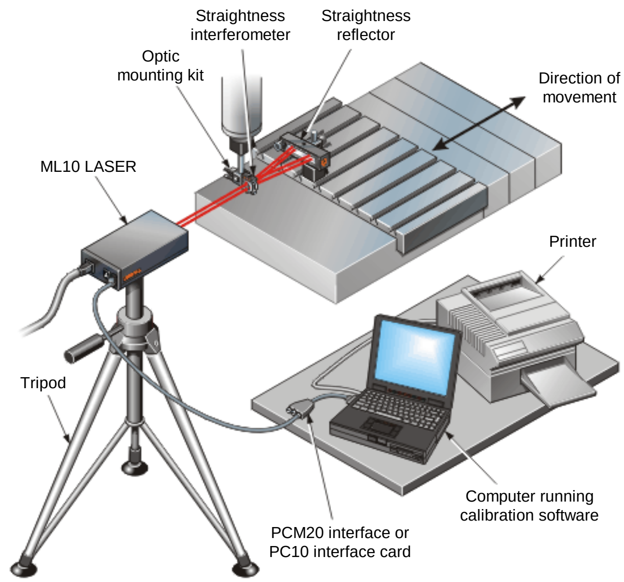

Fig. 6. Typical setup for straightness measurement using Renishaw laser system

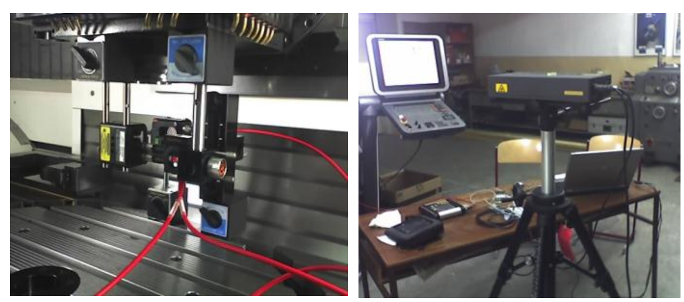

Fig. 7. Real time setup for straightness measurement (left – optics, right – laser head)

After optics are positioned and connected with laser management software the main shaft is moved from point to point 8 times on a 490 mm length. This procedure is repeated 3 times. The distance between target points is 70 mm. Measurement results are given in Table I. Graphical representation is given in Fig. 8. Analysis of measurement results according to German standard VDI 2671 is illustrated on Fig. 9. Maximum deviation on a given length is Umax=0.00436 which is considerably less from allowable 0.02 mm.

This machine is calibrated upon its installation using dial gauge and length gauge. Length gauge is of 300 mm and overall deviation is 0.006 mm, what is in accordance to allowable deviation of 0.02 mm on a 300 mm length.

TABLE I
MEASUREMENT RESULTS (RANISHAW MEASUREMENT SYSTEM)

Run	Direction	Target	Target value, mm	Actual reading, mm
1	(+)	1	0.0000	0.0005
1	(+)	2	70.0000	0.0002
1	(+)	3	140.0000	0.0021
1	(+)	4	210.0000	–0.0009
1	(+)	5	280.0000	–0.0023
1	(+)	6	350.0000	–0.0011
1	(+)	7	420.0000	0.0009
1	(+)	8	490.0000	0.0007
2	(–)	8	490.0000	0.0007
2	(–)	7	420.0000	0.0011
2	(–)	6	350.0000	–0.0012
2	(–)	5	280.0000	–0.0023
2	(–)	4	210.0000	–0.0009
2	(–)	3	140.0000	0.0018
2	(–)	2	70.0000	0.0005
2	(–)	1	0.0000	–0.0001
3	(+)	1	0.0000	–0.0004
3	(+)	2	70.0000	0.0003
3	(+)	3	140.0000	0.0017
3	(+)	4	210.0000	–0.0008
3	(+)	5	280.0000	–0.0022
3	(+)	6	350.0000	–0.0007
3	(+)	7	420.0000	0.0014
3	(+)	8	490.0000	0.0009
4	(–)	8	490.0000	0.0009
4	(–)	7	420.0000	0.0011
4	(–)	6	350.0000	–0.0010
4	(–)	5	280.0000	–0.0021
4	(–)	4	210.0000	–0.0006
4	(–)	3	140.0000	0.0012
4	(–)	2	70.0000	–0.0001
4	(–)	1	0.0000	0.0004
5	(+)	1	0.0000	–0.0003
5	(+)	2	70.0000	0.0004
5	(+)	3	140.0000	0.0017
5	(+)	4	210.0000	–0.0012
5	(+)	5	280.0000	–0.0026
5	(+)	6	350.0000	–0.0010
5	(+)	7	420.0000	0.0011
5	(+)	8	490.0000	0.0009
6	(–)	8	490.0000	0.0009
6	(–)	7	420.0000	0.0012
6	(–)	6	350.0000	–0.0009
6	(–)	5	280.0000	–0.0026
6	(–)	4	210.0000	–0.0006
6	(–)	3	140.0000	0.0018
6	(–)	2	70.0000	0.0006
6	(–)	1	0.0000	0.0003

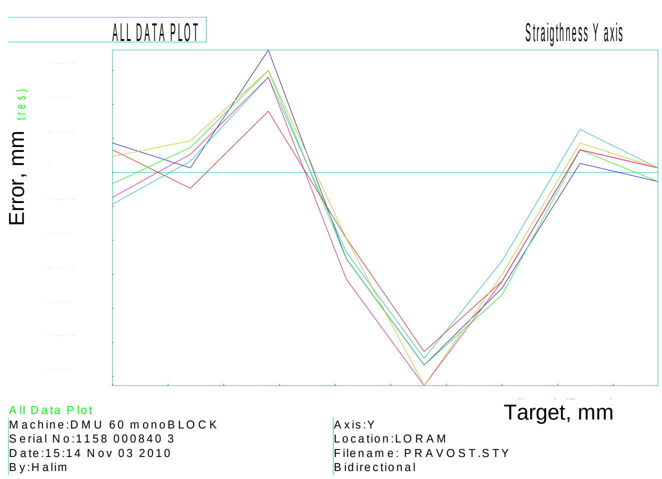

Fig. 8. Graphical presentation of measurement results (Renishaw laser measurement system)

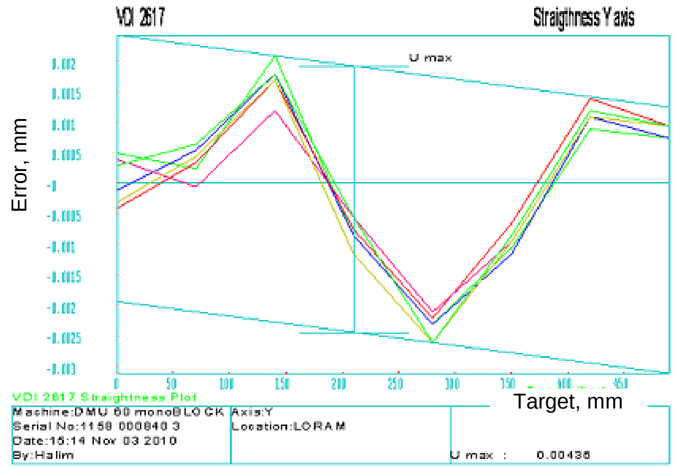

Fig. 9. Data analysis according to German standard VDI 2617

C. *Measurements performed using Damalini laser system*

Way of optics setup for DAMALINI laser system is shown in Fig. 10. Same movement as with RANISHAW laser system is checked. For straightness measurement this laser system uses to heads denoted with marks “M” and “S”.

Head denoted with mark “M” is positioned on a main shaft which is performing movement in direction of Y axis. Head denoted with mark “S” is positioned on a machine bed, and it is stationary had which represent end point of reference axis. Disadvantage of this system is that reference axis is positioned between first and last point of the same movement which is under consideration. That is clearly visible from measurement results, according to which deviation in first and last point is 0. On contrary Renishaw laser system measures deviation in all target points. Measurement results, acquired using DAMALINI laser system, are shown in Fig. 11 and Table II. According to data given in Table II, maximum straightness deviation is 0.004 mm.

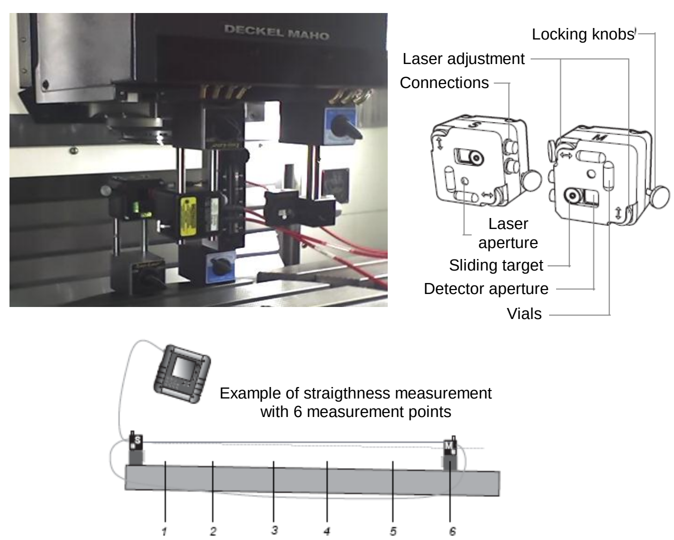

Fig. 10. Damalini laser system setup

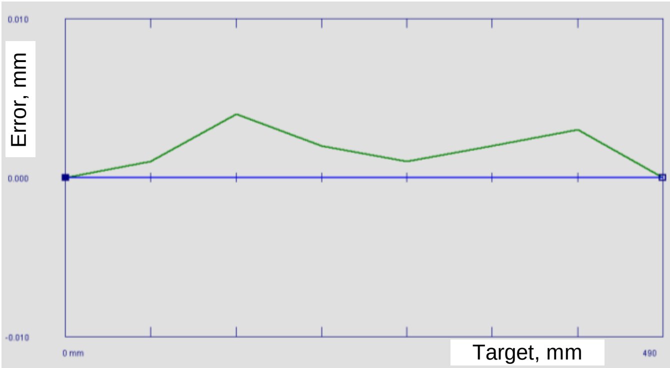

Fig. 11. Graphical presentation of measurement results (Damalini laser measurement system)

TABLE II
MEASUREMENT RESULTS (DAMALINI MEASUREMENT SYSTEM)

Point	Reference point	Distance, mm	Vertical deviation, mm
1	Ref.	0	0.000
2		70	0.001
3		140	0.004
4		210	0.002
5		280	0.001
6		350	0.002
7		420	0.003
8	Ref	490	0.000
Max		0	0.004
Min		0	0.000

IV. CONCLUSION

Straightness measurements procedure on a given machine tool, using two laser systems with different laser beam detection principle, is presented in this paper. Both laser systems showed that straightness deviation of Y axis on a given length is considerably less then allowable according to machine tool manufacturer specification which is 0.02 mm on a 300 mm length. Renishaw laser system gave more "precise" results with more decimal places comparing to Damalini laser which is limited to 3 decimal places (microns). On the other hand setup procedure for DAMALINI laser system is much easier, take less time and still can give results in microns. This Damalini level of precision will meet calibration requirements for a number of machine tools systems. Yet for more precise calibration, in case of CMM for example, Renishaw systems offer significant advantage. When versatility of measurements are considered Renishaw system understandably gave more flexibility, since one have to keep in mind that this system is mainly aimed to machine tools calibration purposes. Additional difference between these two of laser systems is that for Damalini sensors must be connected with cable. It means that measuring length is limited by length of cables, which is not the case when measures with Renishaw system.

According to above mentioned, one can conclude that both of the presented systems can gave significant help in regular machine shop maintenance activities. Yet the correct choice of measuring system have to take into consideration many other elements like purpose of a measured machine tool, requested accuracy and precision, place of a machine in production chain, available time, price of a machine and costs of maintenance.

For future research it would be very interesting to examine the differences in the results of measurements of different characteristics, such as squareness, parallelism, flatness of work table surfaces and so on. Demonstrated two methods of measuring the accuracy of machine tools have, as noted above, their advantages and disadvantages. Therefore, it is necessary to precisely analyze which of the observed measurement methods appropriate to specific situations, the measurements, and also the comparison analysis of the accuracy of machine tools with one hand, and coordinate measuring machines on the other.

REFERENCES

[1] M. Cedelnik, M. Sokovic, J. Jurkovic, "Calibration and Checking the Geometrical Accuracy of a CNC Machine-Tool," *Journal of Mechanical Engineering*, vol. 52, 11, pp. 752-762, 2006.
[2] Y. Kakino, Y. Ihara, Y. Nakatsu, "The measurement of motion errors of NC machine tools and diagnostics of their origins by using telescoping magnetic Ballbar method," *Annals of CIRP*, vol.36, 1, pp.377-380, 1987.
[3] K. Iwasawa, A. Iwamaa, K. Mitsui, "Development of a measuring method for several types of programmed tool paths for NC machine tools using a laser displacement interferometer and rotary encoder," *Precision Engineering*, vol.28, pp. 399-408, 2004.
[4] J. P. Choi, B.K. Minb, S. J. Lee, "Reduction of machining errors of a three-axis machine tools by on-machine measurement and error compensation system," *Journal of Materials Processing Technology*, vol. 155-156, pp. 2056-2064, 2004.
[5] S. L. Omirou, M. M. Fyrillas, "High precision CNC machining of axisymmetric die cavities," *Asian Transactions on Engineering*, vol.02, 05, pp.1-9, 2012.
[6] C. Wang, "5-axis machine tool calibration," *Tooling&Production*,2002.
[7] http://machine-tols.netfirms.com/21_laser_versus_water_jet.htm, Laser beam versus Water Jet Machining.
[8] C. Wang, "Machine tool calibration: standards and methods," *American machinist*, 2009.
[9] RAINSHAW Laser System Manual, 2000-2005 Renishaw plc, Version 7.3.
[10] DAMALINI Easy Laser Measurement and alignment system, Manual 05-0100 Rev 7, 2005.
[11] A.C. Okafor, Y.M. Ertekin, "Vertical machining center accuracy characterization using laser interferometer, Part 1. Linear positional errors," *Journal of Materials Processing Technology*, vol.105, pp. 394-406, 2000.
[12] W. Knapp, "Test of the three-dimensional uncertainty of machine tools and measuring machines and its relation to the machine errors," *ETH Zurich*,pp.459-464, 1993.
[13] J. Kopač, "Concurrent engineering in theory and practice," *Journal of Mechanical Engineering*, vol.49, 12, pp.566-574, 2003.
[14] E.S. Lee, S.H. Suh, Ch.H. Shin, "Performance evaluation of NC controller using a Ball-bar," *Annals of CIRP*, vol.34, 01, pp.402-407, 1985.