INDUSTRIAL APPLICATIONS AND OPTICAL MEASUREMENT TECHNIQUES FOR MACHINE TOOLS

TAKIM TEZGAHLARI İÇİN OPTİK ÖLÇÜM YÖNTEMLERİ VE ENDÜSTRİYEL UYGULAMALARI

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Özet

Takım tezgahlarının (geleneksel ve CNC kontrollü) geometrik doğruluğunun çok hassas bir şekilde kontrol edilmesinin yollarından biri, optik interferometri ölçüm yöntemlerini kullanılmasıdır. Bunlar CNC torna tezgahının (doğrusal hareketten sapma), CNC freze tezgahının (dinamik davranış), derin delme (doğrusallık), CNC freze tezgahının (iki farklı ölçüm yöntemine göre karşılaştırmalı ölçüm doğrusallığı, interferometri ve CCD yöntemi) ölçüm sonuçları karşılaştırılabilmektedir. Takım tezgahları metrolojisinde, takım tezgahlarının lineer ve açısal volümetrik hatalarının ölçülmesinde optik ölçüm yöntemleri kullanılmaktadır. Ölçümlerin ölçeğine ve gereksinimlerine bağlı olarak kullanılan bir dizi farklı yöntem vardır. Bu yöntemler uçuş süresi ölçümlerini, üçgenlemeyi, faz kaydırma yöntemlerini ve interferometriyi içermektedir. Optik komparatörler, imalat endüstrisinde muayene ve ölçüm için kullanılan bir tür optik ölçüm cihazıdır. Optik komparatörler ve ölçüm mikroskopları optik ölçümleri gerçekleştirmek için görüntüleri kullanan temassız optik ölçüm araçlarıdır. Bu makineler, hem hızlı hem de yüksek doğrulukta otomatik ölçümler gerçekleştirmek için görüntü işleme teknolojisini kullanır. Üretim sahalarındaki fabrika otomasyonu istikrarlı bir şekilde ilerledikçe bu ölçüm cihazlarının gelişimi de hızla artmaktadır. Optik komparatörlerin temel özelliği, aynı anda yalnızca tek yönde ölçümle sınırlı olan mikrometreler ve verniyeli kumpaslar veya yükseklik/derinlik ölçerler gibi el aletlerinin aksine, iki boyutlu ölçüm yeteneklerine (X ve Y yönleri) sahip olmalarıdır. Optik komparatörler, ölçümlerini esnek parçaların çarpıtmadan veya hassas parçalara zarar vermeden gerçekleştirebilirler. Muayene işlemi sırasında parçaya ışıktan başka hiçbir şey dokunmaz, dolayısıyla parçanın bükülme veya şekil değiştirme potansiyeli oluşmamaktadır. Optik ölçüm cihazları sadece hassas ölçümleri nedeniyle değil, aynı zamanda üretim hatlarındaki hatalı parçaları kontrol edebilme yeteneklerine sahiptirler. Yeni versiyonları, renkli görüntülerin gözlemlenmesini sağlamak için son derece hassas CCD kameralar kullanmaktadırlar.

Anahtar kelimeler: Takım Tezgahları, CNC, Optik Ölçüm Teknikleri, Lazer İnterferometre, Makine Mühendisliği.

Abstract

Optointerferometry measuring techniques are one approach to carefully regulate the geometric correctness of machine tools (both traditional and CNC operated). These can be compared to the CNC lathe's measurement results (linear motion deviation), the CNC milling machine's measurement results (dynamic behavior), the deep drilling machine's measurement results

(linearity), and the CNC milling machine's measurement results (comparative measurement linearity according to two different measurement methods, interferometry and CNC method). Optical measuring techniques are employed in machine tool metrology to quantify the angular and linear volumetric inaccuracies of machine tools. Several approaches are employed based on the size and specifications of the measurements. Interferometry, phase shifting techniques, triangulation, and time-of-flight measurements are some of these approaches. Optical comparators are a type of optical measuring device used for inspection and measurement in the manufacturing industry. Optical comparators and measuring microscopes are non-contact optical measuring tools that use images to perform optical measurements. These machines use image processing technology to perform automatic measurements that are both fast and highly accurate. As factory automation in production areas progresses steadily, the development of these measuring devices also increases rapidly. The key feature of optical comparators is that they have two-dimensional measurement capabilities (X and Y directions), unlike hand tools such as micrometers and vernier calipers or height/depth gauges, which are limited to measuring in only one direction at a time. Optical comparators can perform measurements of flexible parts without distorting them or damaging sensitive parts. During the inspection process, nothing other than light touches the part, so there is no potential for the part to bend or change shape. Optical measuring devices are important not only because of their precise measurements, but also because they have the ability to check faulty parts in production lines. Newer versions use highly sensitive CCD cameras to enable observation of color images.

Keywords: Machine Tools, CNC, Optical Measurement Techniques, Laser Interferometer, Mechanical Engineering.

1. INTRODUCTION

Periodically verifying the geometric and kinematic correctness of machine tools is one of the most crucial aspects of machine tool maintenance. One of the fundamental requirements for machine tools to operate well is their static and dynamic states. Machine tool specific parameter accuracy can be measured within a suitable time frame to yield the data required to characterize the static and dynamic states of the tools. Conversely, straightness, parallelism, linearity, etc. It may be used to measure geometric deviations and assess the degree of precision of certain machine tools, among other things. The geometric and kinematic correctness of machine tools may be verified and tested using a variety of techniques. One of the most accurate and effective methods is optical methods. Because optical measurement techniques provide a high-precision, non-contact, and flexible means of measuring a wide variety of properties on machine tools, they have gained significant traction in the manufacturing sector. These methods are employed to guarantee the precision and caliber of machined components as well as to track the effectiveness of machine tools over time. Laser triangulation, optical profilometry, vision systems, and laser interferometry are a few of the most widely used optical measuring methods for machine tools.

2. METHOD

The Michelson interferometer divides a light beam into two pathways by use of a beam splitter, which is a partly reflecting mirror. One beam moves in the direction of a stationary mirror, and the other beam reflects off of a moving mirror. The two beams recombine at the beam splitter, creating an interference pattern, after reflecting off the mirrors.

The optical path difference between the two beams determines the interference pattern's strength. Bright interference fringes are produced when the waves reinforce one another and the optical path difference is an integer multiple of the light wavelength. On the other hand, the

waves cancel one other out and create black interference fringes when the optical path difference is an odd multiple of the half-wavelength (physicsbootcam, 2023).

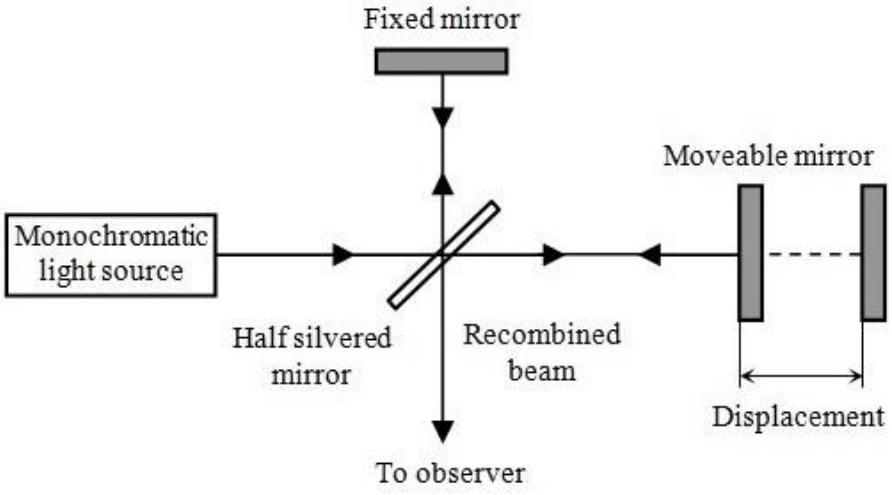


Figure 1. Fundamentals of Michelson interferometer (Begoviç, E., et al., 2014).

As seen in the diagram above, the Michelson interferometer is made up of two mirrors, a half-silvered mirror, and a single wavelength (monochromatic) light source. On the surface, the light source is divided. A mirror at a certain distance receives half of the light's 90° reflection, with the remaining half being let through. Mirrors facing the observer are parallel and reflected. Bright light will arise from constructive interference when all of the mirrors are precisely the same distance from the half-mirror. This means that light will reach the observer in the same phase. The beam will return 180° out of phase to the spectator if the moving mirror is positioned further away, shifting its location by a quarter of a wavelength. This will result in destructive interference and darkness (Begoviç, E., et al., 2014).

As a result, the observer may calculate the distance the moving mirror has gone by counting the light flashes as the mirror travels. Interferometers of today are more sophisticated, measuring distances with accuracy as high as 1 ppm (parts per million), but they still operate on the same essential principles as previously mentioned (Ekinović, S., et al., 2011).

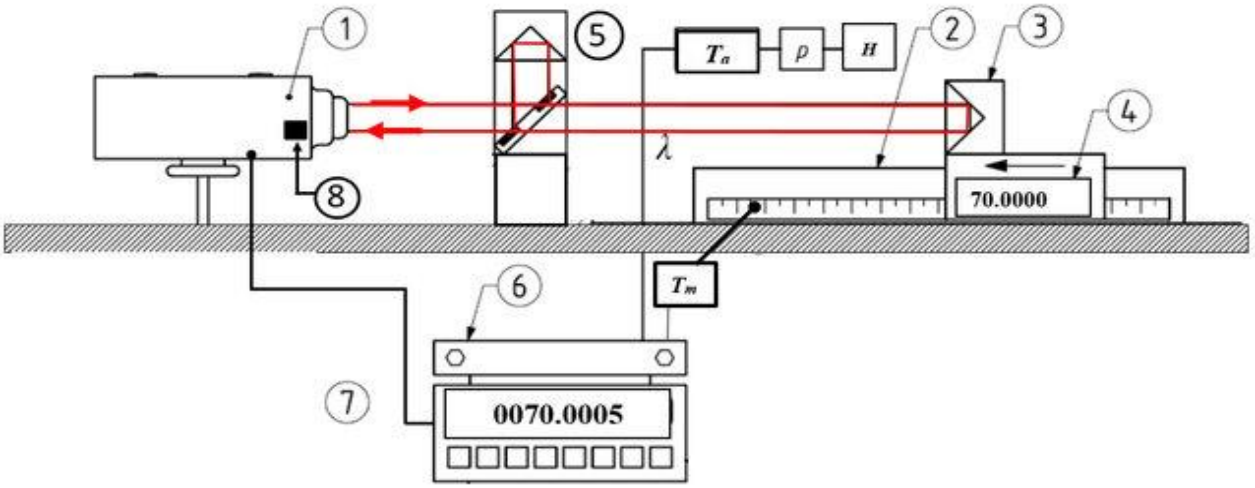


Figure 2. Example of a laser interferometer operation: 1: laser head, 2: slide way, 3: measurement corner-cube, 4: machine-axis reading, 5: beam splitter and reference corner-cube, 6: compensation unit, 7: displacement read-out and 8: photo-detector (Haitjema, H., 2019).

One method for measuring displacement is laser interferometry, which measures light wave interference. It is a very accurate method that can detect displacements down to a fraction of a light wavelength. A common technique for measuring the linear and angular motion of machine tool parts, such slides, spindles, and rotary tables, is laser interferometry. These are a small sampling of the numerous optical measuring methods applicable to machine tools. The approach selected will rely on the application's particular measuring needs. The industrial sector uses a variety of other optical measurement techniques in addition to those already listed. These consist of infrared thermography, Raman spectroscopy, fluorescence spectroscopy, and ultrasonic testing (Haitjema, H., 2019).

3. FINDINGS

Optical measurement techniques are employed in various industrial applications, including: Dimensional metrology: Ensuring that machined items fulfill design specifications requires precise measurement of their dimensions. Measurements of length, width, height, and other dimensions may be obtained precisely using optical methods like laser interferometry and vision systems.

Geometric Error Compensation: As a result of wear and tear, machine tools may eventually acquire geometric flaws. Optical methods like as coordinate measurement machines (CMMs) and laser trackers can detect and measure these inaccuracies, enabling better machining precision and adjustment.

Surface Inspection and Profiling: To evaluate the surface quality of machined items, optical methods such as optical profilometry and laser triangulation are employed. In order to make sure that components fulfill the necessary surface finish criteria, they can measure surface roughness, texture, and flaws.

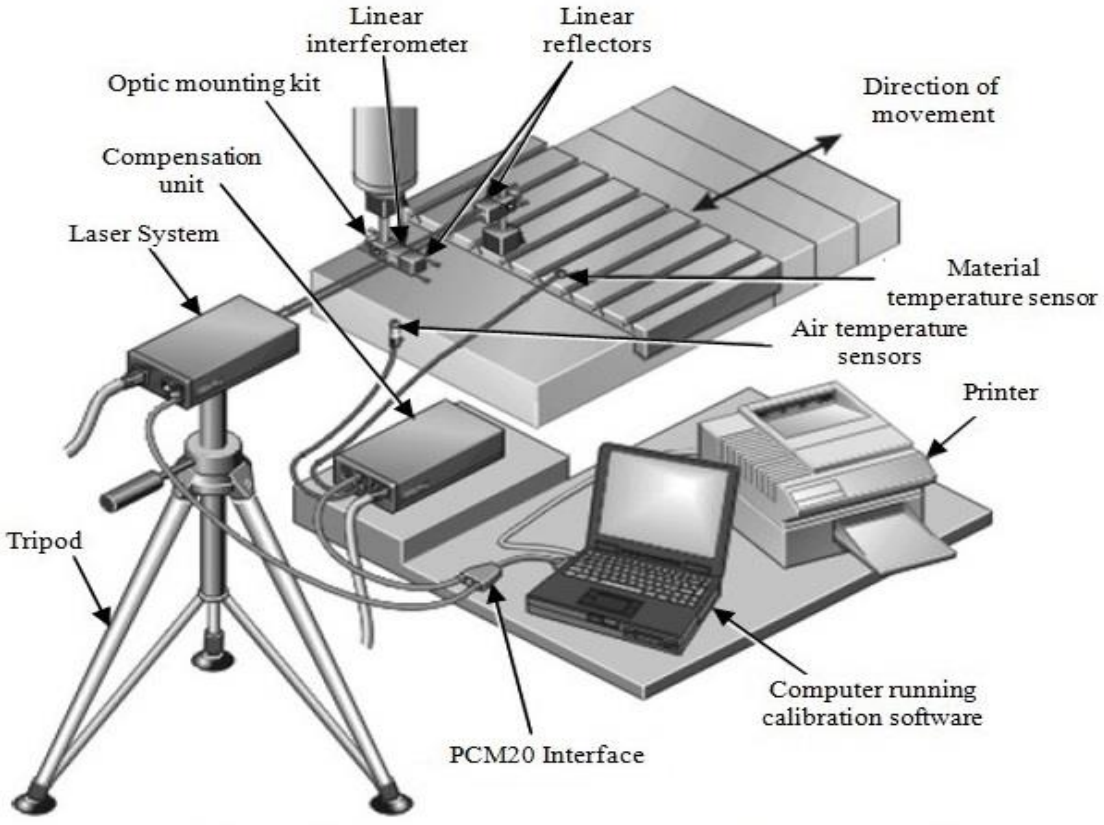
Tool Wear Monitoring: By using optical methods like as laser scanners and vision systems, it is possible to track tool wear in real time and identify worn or damaged tools before they lead to machined component flaws. This proactive strategy aids in reducing scrap and production downtime (acuitylaser.com, 2023).



Figure 3. QM-109 Feat. Measurement P1FT-QV-Stream, example of advanced non-contact measurement technology (qualitymag.com, 2023).

Benefits of Optical Measurement Techniques. Optical measurement techniques offer several advantages over traditional contact-based methods: Non-contact: Eliminates the risk of damage to delicate parts and ensures minimal interference with the machining process. High Precision: Capable of measuring features with high accuracy, often achieving sub-micron resolution. Versatility: Can measure a wide range of features, including dimensions, shape, surface texture, and tool wear. Speed: Many optical techniques provide real-time measurements, enabling rapid process monitoring and control. Data Acquisition and Analysis: Optical systems can generate comprehensive data sets that can be analyzed using specialized software for in-depth inspection and quality control. Impact on Manufacturing Optical measurement techniques have significantly impacted the manufacturing industry by: Improving Part Quality: Precise measurements ensure machined parts meet design specifications, reducing defects and scrap. Optimizing Machine Performance: Real-time monitoring of tool wear and machine motion helps optimize machining parameters and extend tool life. Enhancing Process Control: In-process monitoring enables adaptive machining, adjusting parameters based on real-time feedback. Reducing Production Time: Non-contact measurements minimize downtime and enable faster inspection and quality control.

Enabling Automation: Optical techniques can be integrated into automated manufacturing systems for consistent and reliable quality control. Future Outlook: As technology advances, optical measurement techniques are expected to continue evolving and expanding their capabilities: Miniaturization: Smaller and more compact optical sensors will enable integration into smaller machine tools and robotic systems. High-Speed Imaging: Faster image acquisition and processing will enable real-time defect detection and process optimization. Multispectral Analysis: Combined with machine learning algorithms, multispectral analysis will provide deeper insights into material properties and defects. Digital Twins: Integration with digital twin



technology will enable virtual simulations of machining processes for predictive maintenance and optimization. Artificial Intelligence: AI-powered analysis of optical data will automate defect classification and provide intelligent process control (Benbarrad, T., et al., 2021) (B. Rosa, et al., 2015).

Figure 4. Standard system configuration for linear position measurement (Begovic, E., et al., 2014).

The standard system configuration for linear position optical measurement typically consists of the following components: Light Source: A stable and coherent light source, such as a laser or LED, is used to generate the light beam that is used for measurement. Beamsplitter: A beamsplitter is a partially reflective mirror that splits the light beam into two paths. One path goes to the reference mirror, and the other path goes to the measurement mirror. Reference Mirror: The reference mirror is a fixed mirror that reflects the light beam back to the beamsplitter. Measurement Mirror: The measurement mirror is attached to the object whose position is being measured. The light beam reflects off the measurement mirror and back to the beamsplitter. Detector: The detector is a device that converts the light beam into an electrical signal. The intensity of the electrical signal is proportional to the optical path difference between the two light paths. Data Acquisition System: A data acquisition system is used to collect and analyze the electrical signal from the detector.

The data acquisition system can output the position of the object in real time. In addition to these core components, the system may also include additional components, such as: Optics: Lenses, prisms, and other optical components can be used to focus the light beam, change its direction, or filter out unwanted wavelengths. Electronics: Electronic circuits are used to amplify and process the electrical signal from the detector. Software: Software is used to control the system, collect and analyze data, and display the results. The specific components and configuration of the system will vary depending on the specific application. For example, a system for measuring the position of a stage in a microscope will be different from a system for measuring the position of a machine tool (Santoso, T., et al. 2022) (N. Bosmans, et al., 2017) (W. Gao, et al., 2019) (W.P.Syam, et al., 2019).

4. RESULT, CONCLUSION AND SUGGESTIONS

Thanks to its ability to provide accurate measurements, real-time monitoring, and enhanced quality control, optical measuring techniques have emerged as vital instruments in the industrial sector. They are perfect for a variety of industrial applications because to their non-contact nature, great precision, and adaptability, which guarantees the creation of high-quality machined components and preserves the effectiveness of machine tools. As fully automated and CNC machine tools evolved, extremely accurate measurement parameters became necessary. The primary characteristics of contemporary machine tools are accuracy and precision. For many years, standard measuring techniques have been employed to identify and characterize certain features of machine tools. However, the movements' straightness, consistency, levelness of surface, parallelism, etc. There are other more sophisticated methods and tools available, including laser measuring systems, to measure machine characteristics like (comparative measurement linearity according to two separate measurement methods: interferometry and CCD technique. Regular maintenance Tasks in machine shops can be greatly aided by these findings. Thus, selecting the appropriate measurement tool and technique may help save time and lower the cost of equipment maintenance. Optical measuring techniques are expected to maintain their crucial position in the manufacturing sector, propelling innovation. , efficiency, and precision in the creation of superior machined components. However, choosing the right measuring system requires taking into account many factors such as the purpose of the

machine tool being measured, the desired accuracy and precision, the place of the machine in the production chain, available time, the price of the machine and maintenance costs.

5. REFERENCES

B. Rosa, P. Mognol, J.-Y. Hascoet, Laser polishing of additive laser manufacturing surfaces, J. Laser Appl., 27 (2015), https://doi.org/10.2351/1.4906385

Begovic, E., Plancic, I., Ekinovic, S., Ekinovic, E., Laser Interferometry-Measurementand Calibration Method for Machine Tools, 3rd Conference "MAINTENANCE 2014"Zenica, B&H, June 11 – 13, 2014.

Benbarrad, T., Salhaoui, M., Kenitar, S. Intelligentmachine vision model for defective product inspectionbased on machine learning. Journal of Sensor and Actuator Networks, Published by MDPI, Online ISSN: 2224-2708, January 2021, https://doi.org/10.3390/jsan10010007

Ekinović, S., Ekinović, E., Prcanović H., Begović E.: „Example of Determining Faults on CNC Milling Machine Using Renishaw Laser Calibrating system", Journal of Mechanical Engineering and Production Management, Politechnika Poznanska, Poznan, Nr.1 (15): 55-64., 2011.

Haitjema, H., Calibration of Displacement Laser InterferometerSystems for Industrial Metrology, Sensors 2019, https://doi.org/10.3390/s19194100.

http://www.physicsbootcamp.org/section-michelson-interferometer.html read 25.11.2023.

https://www.acuitylaser.com/sensor-resources/measurement-principles/ read 26.11.2023.

https://www.qualitymag.com/articles/95709-choosing-the-optical-measurement-device-thats-right-for-you read 24.11.2023.

N. Bosmans, J. Qian, D. Reynaerts, Design and experimental validation of an ultra-precision Abbe-compliant linear encoder-based position measurement system, Prec. Eng., 47 (2017), pp. 197-211.

Santoso, T., Syam, W. P., Darukumalli, S. and Leach, R. (2022) 'Development of a compactfocus variation microscopy sensor for on-machine surface topography measurement', Measurement: October 2022, Measurement 187, https://doi.org/10.1016/j.measurement.2021.110311

W. Gao, H. Haitjema, F.Z. Fang, R.K. Leach, C.F. Cheung, E. Savio, J.M. Linares, On-machine and in-process surface metrology for precision manufacturing, Ann. CIRP, 68 (2019), pp. 843-866.

W.P. Syam, K. Rybalcenko, A. Gaio, J. Crabtree, R.K. Leach, Methodology for the development of in-line optical surface measuring instruments with a case study for additive surface finishing, Opt. Lasers Eng., 121 (2019), pp. 271-288.