Analyzing Vibration Characteristics: A Comparative Study of Laser vs. Spindle Systems

Mohammed F. Farhan[1a], Suhad D. Salman[1b], Z. Leman[2], M.F.M. Alkbir[3a] and Fatihhi Januddi[3b]

Authors affiliations:
1) Mechanical Engineering Department, College of Engineering, Almustansiriyah University, Baghdad, Iraq.
a)mohammedfarkedfarhan@gmail.com
b)suhad.d.salman@uomustansiriyah.edu.iq

2) Department of Mechanical and Manufacturing Engineering, Faculty of Engineering, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia.
zleman@upm.edu.my

3) Facilities Maintenance Engineering, UniKL Malaysian Institute of Industrial Technology (MITEC), Persiaran Sinaran Ilmu, Bandar Seri Alam, 81750 Masai, Johor Darul Takzim, Malaysia
a) munir@unikl.edu.my
b) mohdalfatihhi@unikl.edu.my

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Abstract

In the field of engineering, 3D printers are indispensable due to their high precision. This study focuses on the construction and optimization of a 3D printer using aluminum T-slotted bars for the frame, Raspberry Pi 4 for control, and Lightburn software for image printing and machine control. After assembling the main components and programming with Marlin firmware, the machine was tested for vibration and noise reduction. The research compared the vibration of a diode laser and spindle during printing, revealing significantly lower vibration with the laser compared to the spindle. These findings demonstrate the effectiveness of the constructed 3D printer in reducing vibration and noise during operation.

Keywords: 3D Printers, Optimization, Aluminum T-Slotted Bars, Raspberry Pi 4, Lightburn Software, Marlin Firmware, Vibration Reduction, Noise Reduction, Diode Laser, Spindle Vibration.

تحليل خصائص الاهتزاز: دراسة مقارنة بين أنظمة الليزر والسبندل

محمد فرقد فرحان،.سهاد داود سلمان، ز. لمان، منير الكبير، فتحي جنودي

الخلاصة:

تعتبر الطابعات ثلاثية الأبعاد مهمة في الصناعات الهندسية بسبب الدقة العالية لهذه الآلات و استخداماتها المتعدده. من أجل تحسين و تطوير الطابعة الثلاثية الأبعاد تم تصميم و تصنيع طابعه ثلاثيه من قضبان الألمنيوم المشقوقة على شكل حرف T لبناء إطار الآلة، ولوحة الذكاء الاصطناعي raspberry pi 4 في الطابعة ثلاثية الأبعاد للتحكم. البرنامج المستخدم للطابعة ثلاثية الأبعاد هو Lightburn ويستخدم لطباعة الصور والتحكم في سرعة وتسارع آلة الطباعة، بعد تجميع المكونات الرئيسية والبرمجة باستخدام البرنامج Marlin، تم اختبار الجهاز من حيث تقليل الاهتزاز والضوضاء. قارن البحث اهتزاز ليزر والسبندل أثناء الطباعة، وكشف عن اهتزاز أقل بكثير مع الليزر مقارنة بالسبندل.

1. Introduction

Recent technological developments in the industrial sector are ushering in a new period of enhanced connectivity and digitalization for industrial systems. The smart factory concept and the Fourth Industrial Revolution (i.e., Industry 4.0) have emerged in recent times to represent a manufacturing paradigm focused on technology. This paradigm aims to decentralize production processes while enabling flexibility, agility, customization, and customization. Additionally, Industry 4.0 necessitates a paradigm transition from the conventional lean thinking theory to a production management approach [1]. The most recent innovative technology, three-dimensional (3D) printing, which has already revolutionized Manufacturing, engineering, and product design, holds great promise for transforming medicine. 3D printing facilitates the expeditious transformation of data stored in digital three-dimensional models into tangible entities [2]. Solid free form fabrication, layered manufacturing, additive manufacturing (AM), and rapid prototyping (RP) are additional common names for 3D printing. This technology has found extensive implementation across diverse domains of engineering and biomedicine. Subtractive manufacturing refers to the process by which material is extracted from a solid block in conventional manufacturing methods, typically through the use of milling. On the contrary, 3D printing is an all- encompassing concept that delineates diverse techniques for fabricating objects through the additive manufacturing process (hence the term "additive manufacturing") [3]. Materials scientists have recently directed their attention towards the investigation of three-dimensional printing, which is a catchphrase in the field of materials manufacturing. The exponential growth of this technology in recent years is anticipated to bring about a paradigm shift in the manufacturing industry by facilitating the creation of high-performance materials of the next generation [4].

Additive manufacturing (AM) could be defined as "the process of joining materials to produce component data from 3D models". Frequently successive strata, in contrast to formative and subtractive approaches to manufacturing." To produce three-dimensional geometries, the AM process fuses, cools, and solidifies without the need for intricate molds [5]. There is a growing trend among organizations to pursue fundamental digital transformation, which enables systems to acquire intelligence in order to adapt to the ever-changing dynamics of business and the discerning preferences of customers. In addition, there is an ongoing expectation from customers for business systems to possess the capability to adapt and respond promptly, not only to execute their routine tasks but also to furnish supplementary insights that empower them to make informed and reliable decisions [6]. Artificial intelligence (AI), encompassing machine learning (ML), deep learning (DL), and telecommunications, construction transportation health manufacturing, advertising, and education, are regarded as game-changing technologies. In higher education, AI will play an ever-increasing role because it enables students to approach learning issues in a personalized manner, taking into account their individual experiences and preferences [7]. Artificial intelligence (AI) is a cutting-edge technology that has emerged in the era of the Fourth Industrial Revolution (4IR). It possesses the ability to integrate intelligent systems and human behavior [8].

2. Experimental Work

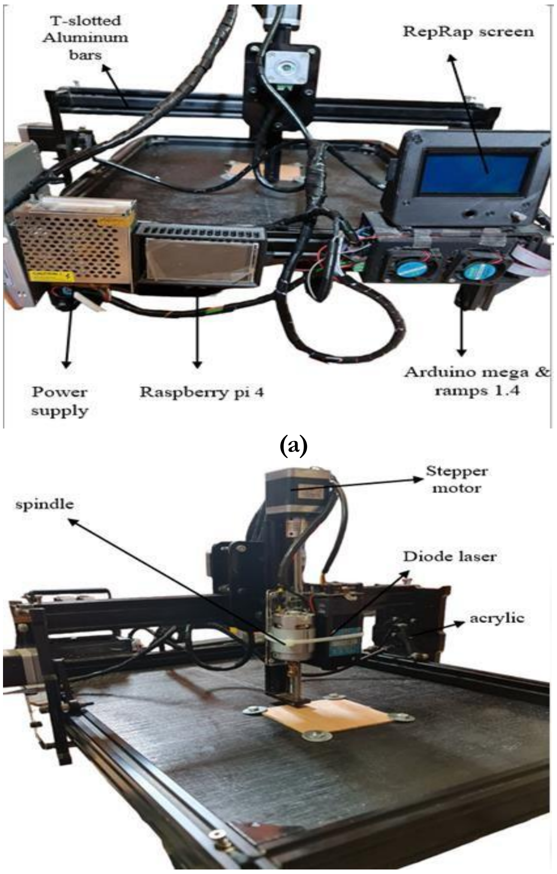
2.1 Diode laser

A laser diode, also referred to as an injection laser diode, diode laser, or LD, is a semiconductor device that functions similarly to a light-emitting diode [9]. It operates by inducing lasing conditions at the junction of a diode through direct electrical current pumping [10]. The doped p–n transition facilitates the recombination of an electron and a hole when it is activated by voltage. Owing to the electron's transition from a higher energy level to a lower one, photon-emitted radiation is produced. Spontaneous emission has occurred. Stimulated emission may result from the process's continued production of light possessing identical phase, coherence, and wave length. The wavelength of the emitted beam is determined by the semiconductor material used, with contemporary laser diodes covering a spectrum spanning from the infrared to the ultraviolet (UV) regions. Laser diodes are the most frequently manufactured form of lasers, and they find application in a variety of fields such as light beam illumination, laser printing, barcode readers, laser pointers, and CD/DVD/Blu-ray disc reading/recording. By employing a phosphor similar to that which is present in white LEDs, laser diodes can be converted into sources of general illumination [11, 12]. Laser diodes are numerically the most common laser types, with 2004 sales of approximately 733 million units, [13] as compared to 131,000 of other types of lasers. [14]

A fixture for retaining a tool (in the case of a milling, grinding, or drilling spindle) or a workpiece (in the case of a turning spindle) affixed to a rotating shaft constitutes a spindle. The tool or workpiece is supported, positioned, and driven rotary by means of the spindle shaft [15]. The spindle shaft is responsible for generating and transmitting the cutting power supplied by an internal or external drive for machining, while enduring any machining forces that arise during the process with minimal deformation. Additionally, it must demonstrate exceptional positioning and operating accuracy. Machine tools employ a diverse range of primary spindles in order to fulfill specific criteria. Milling and drilling spindles are utilized (in part) at high velocities amidst fluctuating operating conditions, whereas turning and grinding spindles must attain extremely high concentricity at a high stiffness and typically at medium speeds [15]. Speed Range: 20,000-60,000 RPM. [16, 17] Materials that spindles work with include embroidery, foam, and glass, wood. [18].

2.2 Building process

Building the 3d printing machine is initiated after preparing its main parts as shown in Figure 1 which include the aluminum bars 70x50 cm to make the machine frame, the aluminum bars will be cut and jointed together using Corners and that'll be Y axis , cutting the rest to make the X axis, both axis are installed to an acrylic parts 10mm in thickness to reduce vibration in the machine, these parts are designed in fusion 360 , Z axis has been designed using aluminum bars, acrylic and 3d printed parts its adjustable its height can be controlled. After that a rubber feet will be installed to absorb vibration from the 3d printing machine during the printing process the stepper motors will be installed on X, Y, and Z axis, a unique parts have been designed and manufactured in fusion 360 and installed in the aluminum bars, and all of the parts used to build this machine like the acrylic designs are all originally designed and manufactured using fusion 360 and Cura, after the mechanical part is done, the programing part will begin by preparing the Arduino mega and shield ramps 1.4 and the unique part about these board they're a 3d printer boards that've been programmed to operate with the diode laser and the spindle, the programming language used is marlin after writing the code, it'll be uploaded to the Arduino mega, the shield will be installed on the Arduino, and the stepper motor drivers will be installed on the shield the unique part about these drivers they're silent and therefore the stepper motors will be silent. After finishing the programming part, a power supply is needed to make the machine work a 12V and 5A power supply is installed to the machine. After this stage the 3d printing machine is done a diode 5.5W laser and a spindle 3000rpm are installed to Z axis and connected to the shield and is ready to print. Raspberry pi 4 8GB is also installed to this machine and programmed its operation system is Linux OS and all of the necessary programs used to control the machine like Lightburn, Arduino IDE, cura and Repetier host. Then the raspberry pi is connected to the Arduino this machine has three control systems the first one is to connected the machine directly to pc or a laptop and the second control system is an lcd connected to the ramps 1.4, the lcd has SD port so the print sample can be transferred to the machine directly. The last method is to connect the raspberry pi to the Arduino and print using the software that've been downloaded to the raspberry pi. The AI part of this machine is a limit switch added to Z axis and programmed to adjust the height automatically when it touches a certain wood thickness, the limit switch level is even with the Wurth of the spindle so it'll adjust the printing level according on that. The laser beam can be adjusted by turning the screw on the laser to get a thinner beam to print accurately.



(a)

(b)

Figure (1): Machine parts.

2.3 Spindle and laser vibration

Using sw-420 sensor to measure the vibration as shown in Figure 2 for both spindle and diode laser, the sensor has been programmed using Arduino and C++ language, after finishing the programming process for the sensor , the sensor will be installed to the laser first doing 20 printing speed sample to measure the vibration of the diode laser the power of the laser was on a 100% and the machine's acceleration is fixed at 6000mm/s^2 the lowest vibration value for the laser was 166 Hz at 7000 mm/min and the machine was stable during the printing process, after finishing the measuring process for the laser the sensor will be then installed on the spindle was on a full power 3000rpm, doing 20 printing speeds and found that the machine became unstable on most of the printing speeds the lowest vibration value is 664 Hz and the highest is 860 Hz and these vibration values are very high for the machine so it's not suitable for the machine and the laser's vibration is very low compared with the spindle and more suitable.

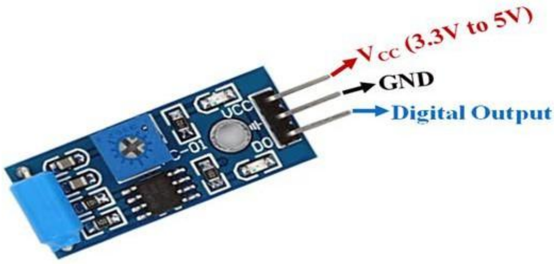


Figure (2): The sw-420 sensor.

3. Results and discussions:

3.1 Laser vs spindle vibration

This study focused on comparing between the diode laser and spindle's vibration during the printing process. The acceleration value is fixed at 6000mm/s^2 and the printing speed is changed, taking 20 printing speed values for the diode laser and the spindle. Starting with 500mm/min and ending with 10000mm/min, the step between each value is 500. Using SW-420 vibration sensor programming it using Arduino Uno and installing it on the diode laser to take the reads, the diode laser is set on full power which is 5.5 watts. Installing the sensor on the diode laser to measure the vibration on the module, the results depend on the vibration duration in 50ms and the vibration in mHz the lowest vibration value is 82707 mHz at 2000mm/min printing speed as shown in Figure (6) but the duration was 43756 ms so it's not suitable because of the vibration time. In Figure (21) at 9500 mm/min the peak value of the vibration was 92519 mHz and the vibration time 22199 ms this reading was suitable compared with the other results because the vibration values were very high as well as the vibration time so they're not suitable the highest vibration value is 761715 mHz at 3000mm/min as shown in Figure (8) 3000rpm. Taking 20 printing speed values to check the vibration of the spindle all the measures had a very high vibration values and it made the machine's axis not stable; the lowest value is 477524 it's very high compared with other values. After finishing the measuring process for the diode laser the sensor then installed on the spindle, the spindle also has been set on full power which is Comparing with the laser module results at 9500 and 3000 mm/min, the spindle vibration at 9500 mm/min is 793462 mHz and the vibration duration is 7680ms, the vibration value is very high and it effected the printing process and the printing quality as shown in Figure (40), and at 3000mm/min the vibration value is 749094 mHz and the vibration time is 9286 ms as shown in Figure (28) [19, 20].

3.1.1 Laser vibration

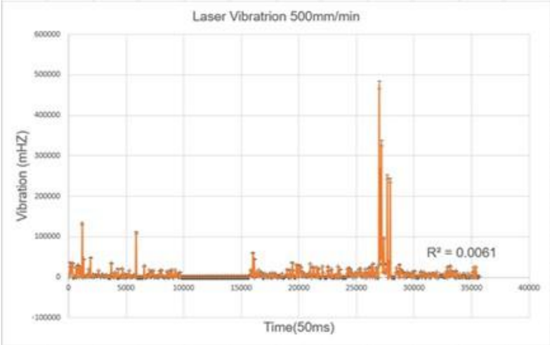


Figure (3): Laser vibration 500mm/min.

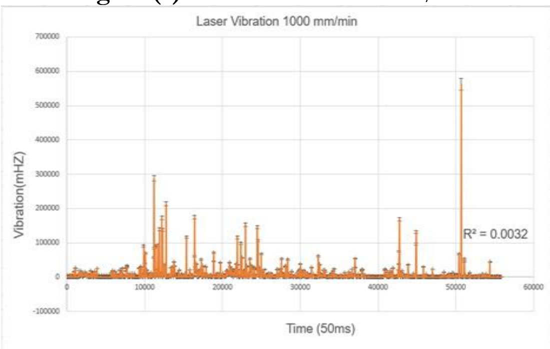


Figure (4): Laser vibration 1000mm/min.

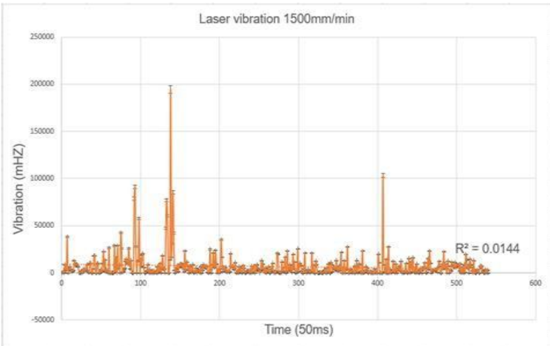


Figure (5): Laser vibration 1500mm/min.

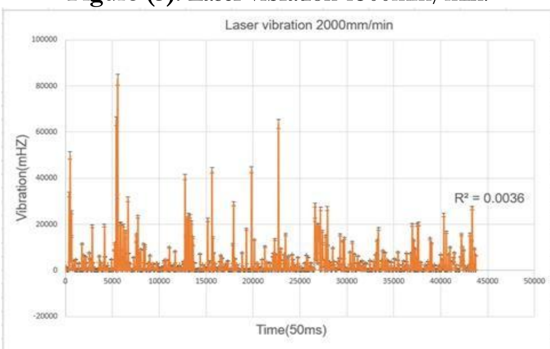


Figure (6): Laser vibration 2000mm/min.

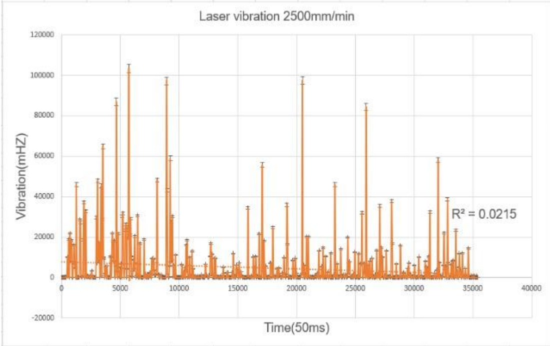


Figure (7): Laser vibration 2500mm/min.

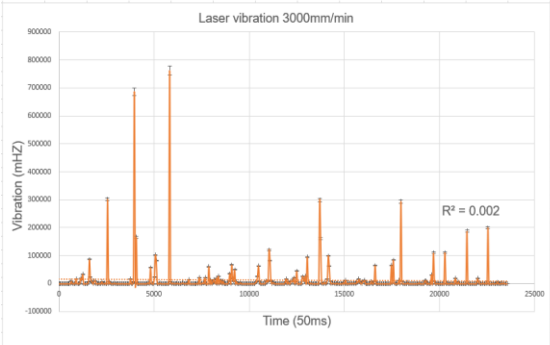


Figure (8): Laser vibration 3000mm/min.

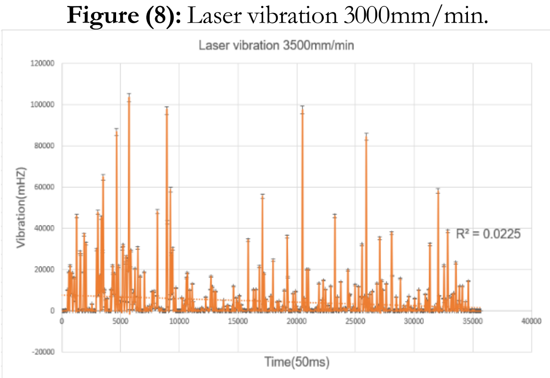


Figure (9): Laser vibration 3500mm/min.

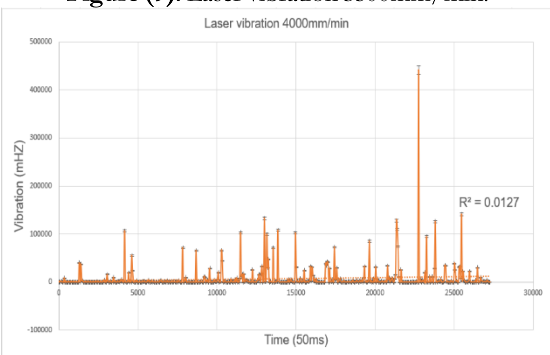


Figure (10): Laser vibration 4000mm/min.

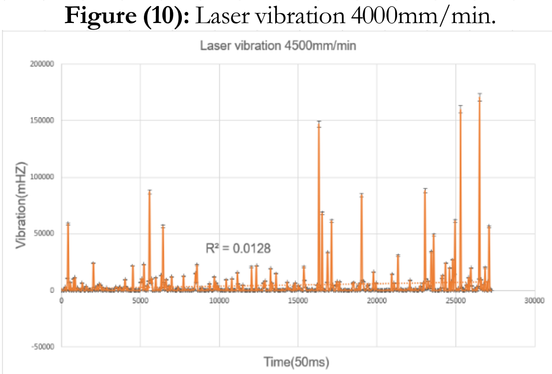


Figure (11): Laser vibration 4500mm/min.

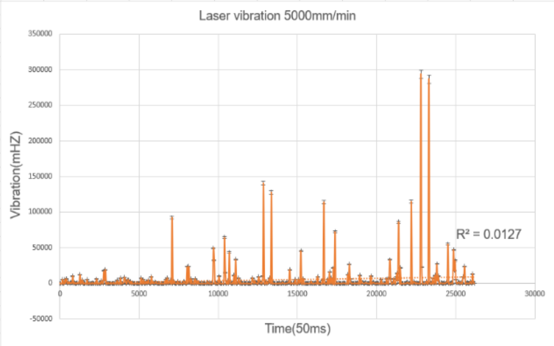


Figure (12): Laser vibration 5000mm/min.

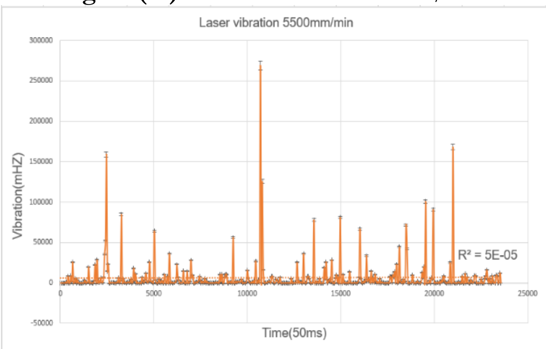


Figure (13): Laser vibration 5500mm/min.

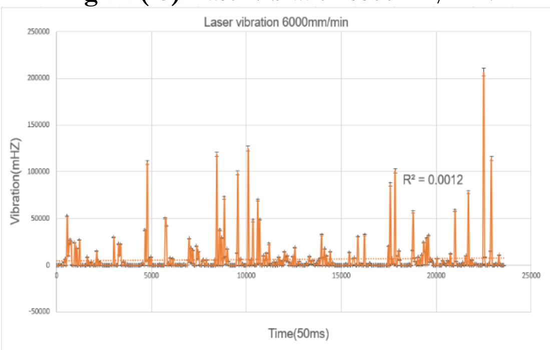


Figure (14): Laser vibration 6000mm/min.

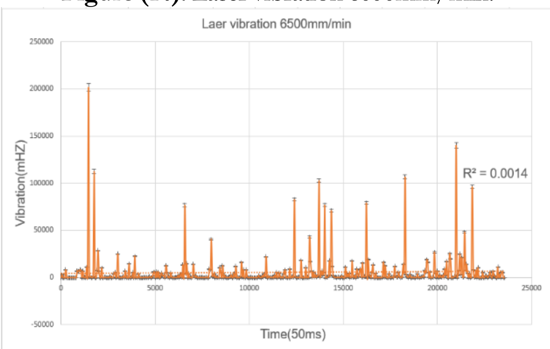


Figure (15): Laser vibration 6500mm/min.

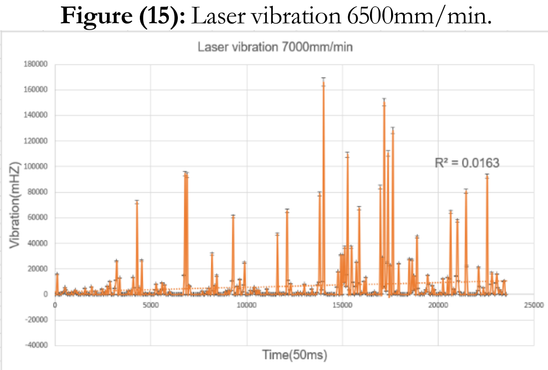


Figure (16): Laser vibration 7000mm/min.

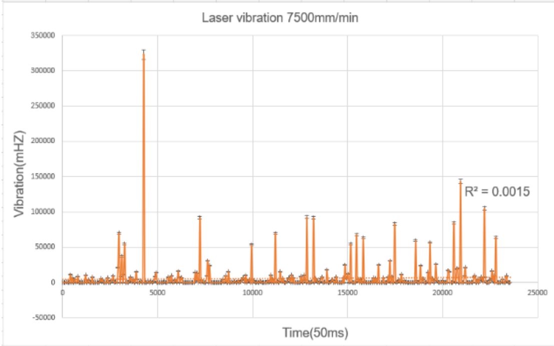


Figure (17): Laser vibration 7500mm/min.

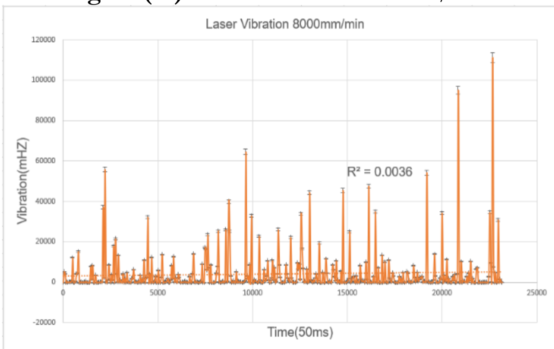


Figure (18): Laser vibration 8000mm/min.

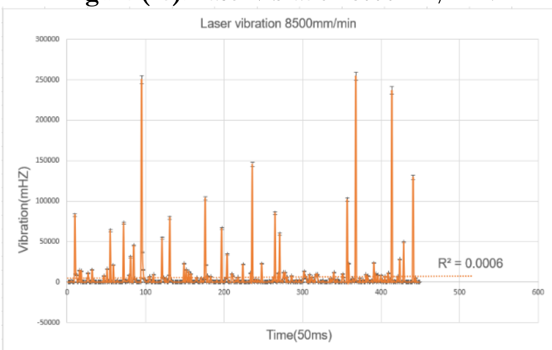


Figure (19): Laser vibration 8500mm/min.

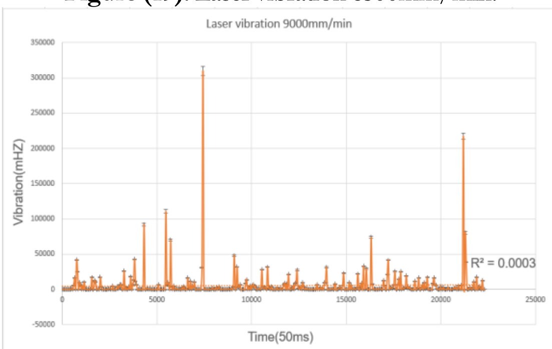


Figure (20): Laser vibration 9000mm/min.

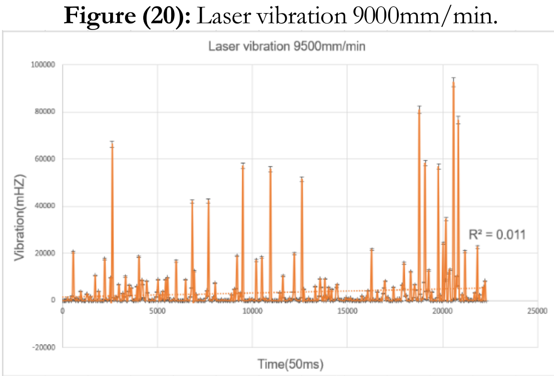


Figure (21): Laser vibration 9500mm/min.

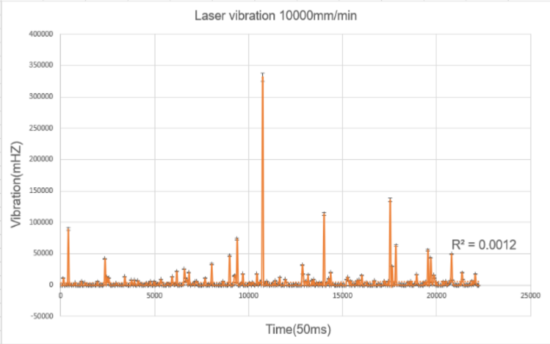


Figure (22): Laser vibration 1000mm/min.

3.1.2. Spindle vibration

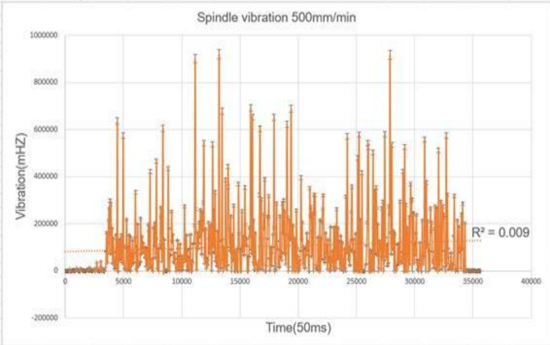


Figure (23): spindle vibration 500mm/min.

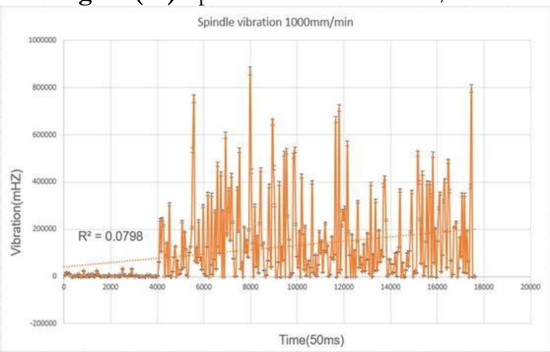


Figure (24): spindle vibration 1000mm/min.

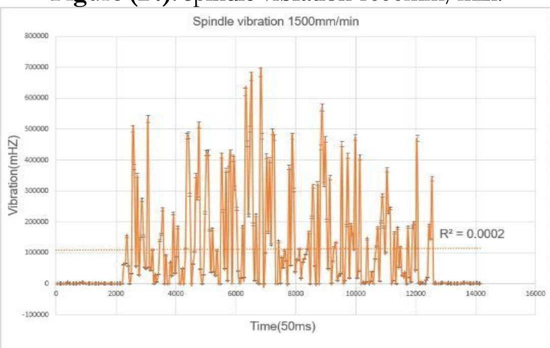


Figure (25): spindle vibration 1500mm/min.

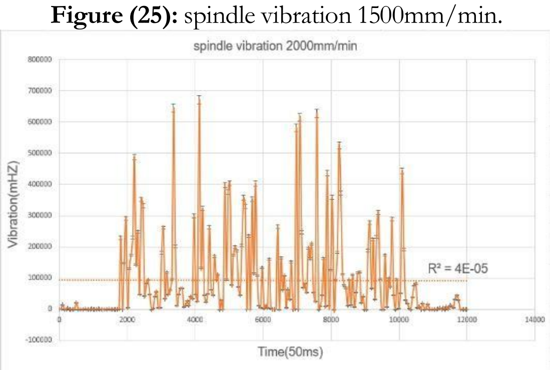


Figure (26): spindle vibration 2000mm/min.

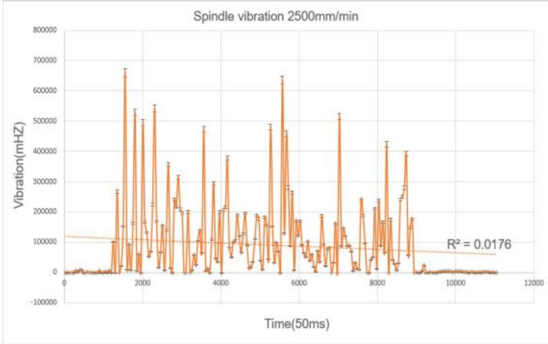


Figure (27): spindle vibration 2500mm/min.

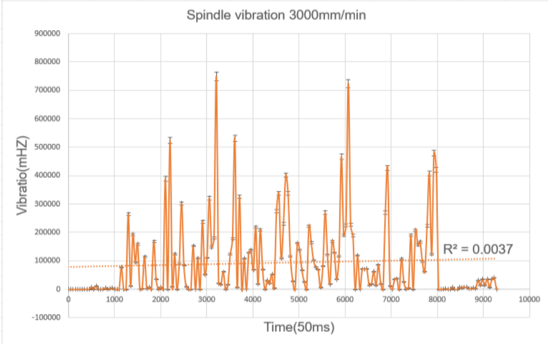


Figure (28): spindle vibration 3000mm/min.

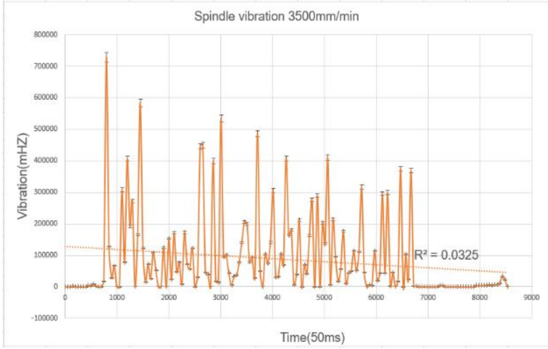


Figure (29): spindle vibration 3500mm/min.

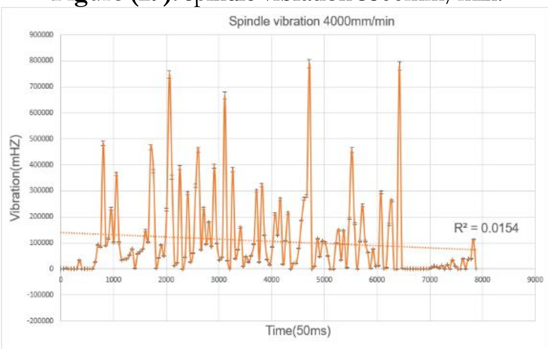


Figure (30): spindle vibration 4000mm/min.

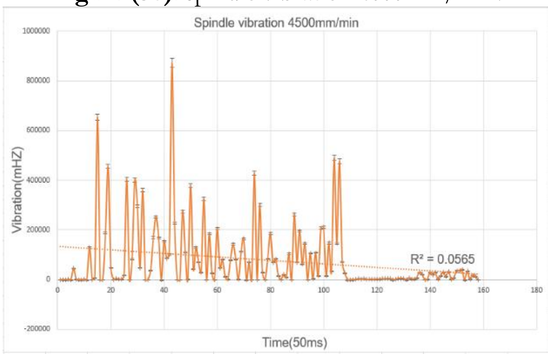


Figure (31): spindle vibration 4500mm/min.

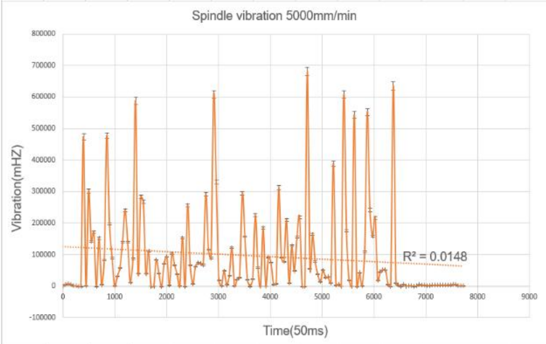


Figure (32): spindle vibration 5000mm/min.

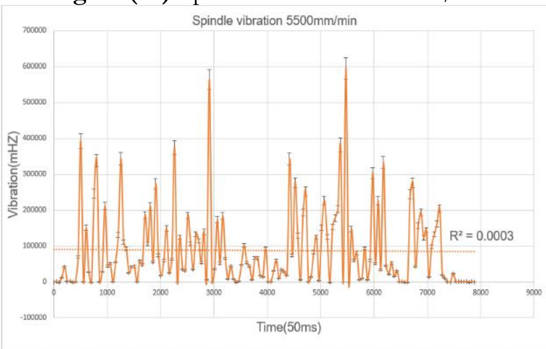


Figure (33): spindle vibration 5500mm/min.

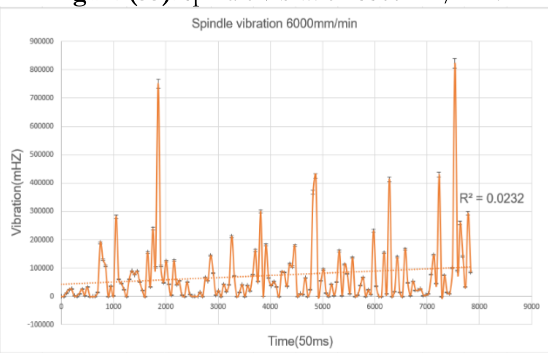


Figure (34): spindle vibration 6000mm/min.

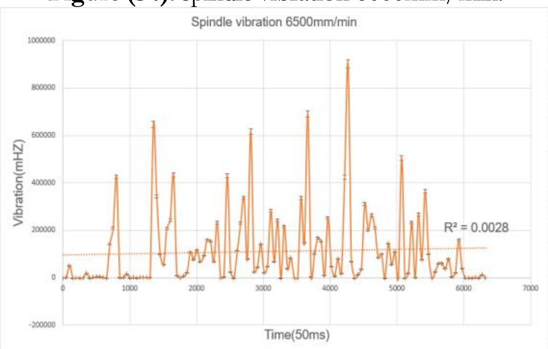


Figure (35): spindle vibration 6500mm/min.

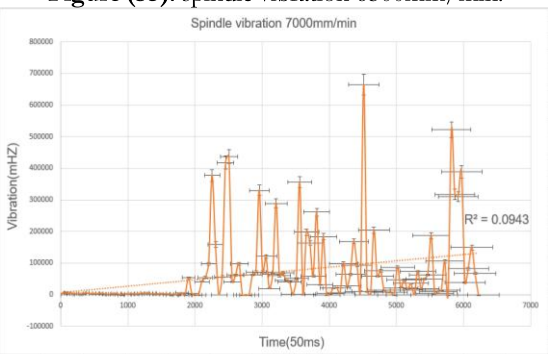


Figure (36): spindle vibration 7000mm/min.

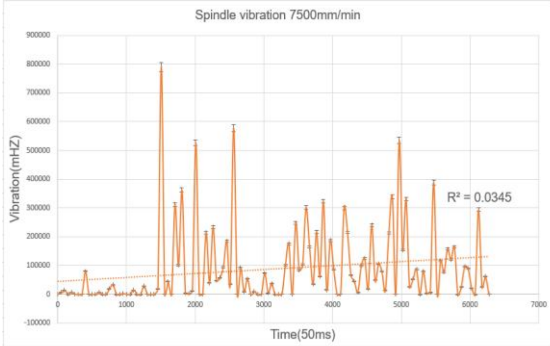


Figure (37): spindle vibration 7500mm/min.

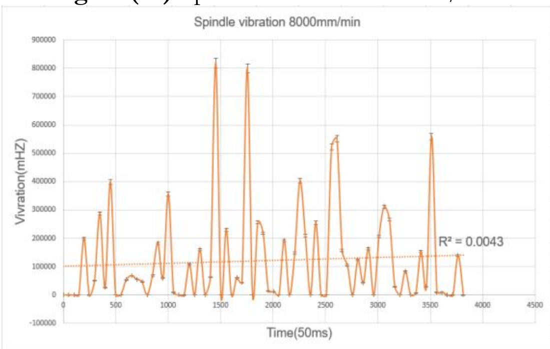


Figure (38): spindle vibration 8000mm/min.

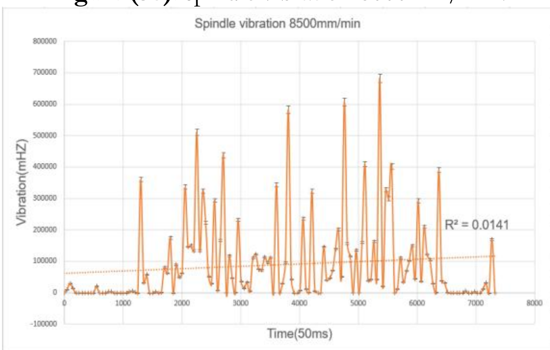


Figure (39): spindle vibration 8500mm/min.

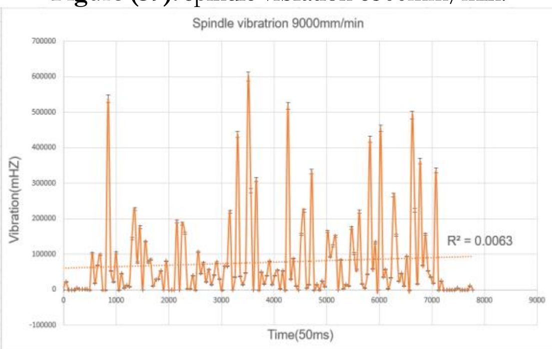


Figure (40): spindle vibration 9000mm/min.

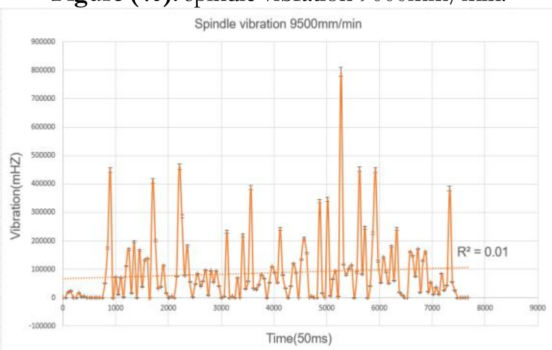


Figure (41): spindle vibration 9500mm/min.

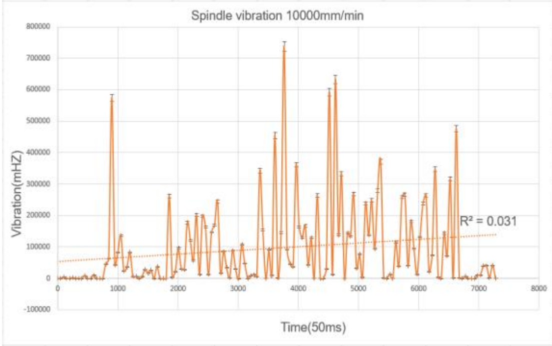


Figure (42): spindle vibration 1000mm/min.

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