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Research Article

Ti6Al4V Malzemesinin Frezelenmesi'nde Oluşan Takım Titreşiminin MEMS İvme Sensörü ile İzlenmesi

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Öz

Talaşlı imalatın hedefi maksimum takım ömrü, kısa üretim zamanı ve az maliyetle, iyi kalitede yüksek üretim miktarı elde etmektir. Bu hedefe ulaşmak için hata tespit ve tahmini büyük öneme sahiptir. Hata tespiti ve tahmini konusunda günümüzde mevcut olan metotların en iyilerinden birisi ivmeölçerler kullanılarak algılanan titreşimin analizidir. Frezeleme anında oluşan mekanik titreşimler, işlenen parçanın yüzey kalitesinin bozulmasına sebep olmaktadır. Bu titreşimleri algılamanın eşzamanlı yapılması, hata oluşmadan önlemlerin alınabilmesine olanak sağlayacaktır. Yapılan bu çalışmada yenilikçi bir teknoloji kullanılarak, frezeleme esnasında takım ucunda meydana gelen titreşimlerin eş zamanlı izlenmesinde kullanılacak bir akıllı takım sistemi geliştirilmiştir. Bu sistem; kesici takım ucundaki titreşimi algılamada kullanılan Mikro Elektro-Mekanik Sistem (MEMS) titreşim sensörü, kablosuz veri haberleşmesini sağlayan Zigbee modülü, sistemi kontrol eden mikrodenetleyici kartı ile besleme grubu ve verilerin alınması, saklanması ve test edilmesi için geliştirilen masaüstü yazılımını içermektedir. Çalışma kapsamında geliştirilen akıllı sistemde takım içerisine yerleştirilmiş olan MEMS ivme sensöründen elde edilen titreşim verileri, kablosuz veri iletim modülleri kullanılarak, uzaktaki bir bilgisayara aktarılmıştır. Geliştirilen yazılımla, alınan veriler eşzamanlı olarak izlenebilmekte, kayıt altına alınabilmekte ve veri analizleri yapılabilmektedir. Sistem kullanılabilir seviyeye getirildikten sonra yapılan teslerle kalibre edilmiştir. Geliştirilen akıllı takım sisteminin minyatür boyutta, düşük maliyetli, düşük güç tüketimli olması, dönen aygıtlara takılabilmesi ve sorunsuz çalışması bu çalışmanın önemini göstermektedir. Bu sistemin takım tutucu başlık üzerine sabitlenmiş olması ve kablosuz veri alışverişine izin vermesi, kesici takım hangi açıda olursa olsun veri gönderiminin kesilmemesini sağlamaktadır. Bu tip akıllı sistemlerin imalat sanayinde kullanımının yaygınlaşmasının, imalat esnasında oluşan sorunların daha kolay tespit edilebilmesinde ve bu sayede üretim sürecinin hızla iyileştirilmesine yönelik çözüm önerilerinin sunulmasında faydalı olabileceği düşünülmektedir.

Anahtar Kelimeler: Talaşlı imalat, Akıllı takım sistemi, Mikro elektro-mekanik sistem (MEMS), Kablosuz veri iletimi

Monitoring of Tool Vibration in the Milling of Ti6Al4V with MEMS Accelerometer

Abstract

The aim of machining is having maximized tool life with short spans of machining white maintaining high value of production, high quality standards and low production costs. The importance of fault detection and estimation is crucial for reaching these aims. One of the best methods of error detection and estimation available today is the analysis of vibration perceived using accelerometers. The vibrations caused by milling a part, effects the surface quality negatively. Simultaneous detection of the vibrations will allow

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correction of machining defects before these defects took place. In this study, using an innovative technology a smart tooling system has been developed which can detect vibrations of the tool-tip simultaneously during milling. This system includes the Micro Electro-Mechanical System (MEMS) vibration sensor used for vibration detection at the end of the cutting tool, the Zigbee module for wireless data communication, the microcontroller card for controlling the system, and the desktop software developed for retrieving, storing and testing the feed group and data. The data that is gained through the micro electro-mechanic system's (MEMS) accelerometer, which is embedded inside the tool, is transferred to a computer via wireless method. With the developed software, the received data can be simultaneously tracked, recorded and data analyzed. After the system is brought to the usable level, it is calibrated by the performed tests. The importance of this study lies in the smart tooling system which is very small, cheap to produce, energy efficient, can be implemented in rotational moving parts and very reliable and problem free. It has been thought that the increase in the usage of these systems in the manufacturing industry can lead to easier detection of the problems which will then be used for developing the solution ideas that will increase the quality of manufacturing processes in short spans of time.

Keywords: Machining, MEMS accelerometer, Intelligent cutting tool system, Wireless data transmission.

1. Introduction

Milling operations, which is an important area in machining, is a versatile manufacturing process and is widely used in industry. Milling operations are carried out by machining the workpiece of the cutting tool connected to a rotating shaft. Depending on the geometry of the cutting tool used in the mill and the geometry of the cutting edges, it has a complicated cutting geometry because it cuts from many points at the same time. Elements used in precision industries, especially in the aviation sector, have narrow tolerance limits (Çolak, 2006). The forces that occur at high cutting speeds and high chip removal rates in the machining of difficult pieces cause the cutting tools to vibrate excessively irregularly during the process. This vibration of the tools causes the cutting tool to break during machining, causing the machining stability and quality to deteriorate. In order to develop a stable machining strategy, the tool and machine vibration model of the tool vibration must be realized. For this, modal analysis of the machine tool pairs were performed and processing solutions were presented in analytical stability regions. However, at the time of processing, irregularities and wear on the tool require real-time monitoring of vibration (Eynian & Altıntaş, 2009). Turning the monitoring and analysis systems into industrial availability in the chip removal process where the tool status can be monitored will make it easier to solve such problems and will be able to pass the material and other material losses in advance (Işık, 2004). Moreover, simultaneous monitoring of vibrations in the toolholder heads during milling will ensure that analysis information is available for immediate detection and resolution of some physical problems that may occur on the workpiece. With this intelligent tool system developed in this study, it is desired to avoid roughness which may occur on the cut workpiece and the cutting tool during surface machining. It is aimed to monitor tool vibrations, which are formed especially during manufacturing of multi-axis machining of expensive materials such as titanium (Ti6Al4V), using wireless data communication and micro electromechanical sensor (MEMS) technology and to improve production process by detecting and analyzing problems during manufacturing. Innovative, cost-effective MEMS sensor data and signal processing technologies are used to achieve this goal. Within this scope, a wireless intelligent tool system has been developed. This system can be used without interfering before errors occur, allowing cutting tools of multi-axis CNC machines to be monitored wirelessly with a MEMS technology-based sensor.

Condition monitoring systems are systems that enable the status information about the operation of the system to be sent to the clients by interpreting the data obtained from an industrial process. These systems have great pre-emption in the process of obtaining data and process control in the industrial process. Preliminary identification of errors that can occur in the system by interpretation of the data is extremely important for economic and safe operation of industrial processes. The use of the status monitor allows for planned protection before an error occurs, avoiding the consequences of an error, or taking other precautions. However, it does not prevent the damage that would occur in case of deviations from the reference value (vibration behavior). When an error is detected, the error has already begun to occur and the status monitoring system may be measuring the occurrence of the deterioration. The interference prior to the formation of the fault ensures that the damage to the machine is greatly prevented. The best way to prevent the malfunctioning is to determine the malfunction without reaching a dangerous situation and stopping the machine's operation while it is in its initial stage. Vibration analysis is the best method available today (Orhan, 2002). Making a vibration monitor online will ensure that precautions can be taken without error. The state tracking methods that can be used in many different scenarios are based on the real-time implementation of decision-making algorithms for the current situation, which can be observed continuously instead of periodic maintenance at specific time intervals (Çalış, 2000).

Rotating machines have a chance of undergoing risk of errors more than non-rotating ones. When wired methods are used in monitoring the status of such machines, it is often possible to encounter limitations. When using wireless systems, there are many other useful aspects, such as the ease of transmitting data and the ability to monitor from a center. The advances in semiconductor technology have enabled the production of lightweight sensors and processors that can be transported in very small sizes, and the availability of wireless data transmission in the industrial field has come to the fore. For this study, ZigBee technology, which uses the IEEE 802.15.4 standard, which is in the forefront with its features such as miniaturized dimensions, low data signalling rate, low noise impact, low energy consumption and low cost, is preferred. ZigBee technology is a new and rapidly evolving technology. In addition, intelligent media applications developed for the preliminary detection of faults are Micro electromechanical system (MEMS) sensors, which are specially prepared and installed by connecting sensors to detect physical events (Somay, 2009). Recent developments in MEMS produce high performance, precise and low cost accelerometers. Acceleration sensors are sensors that convert acceleration from static motion or static gravity to electrical signals (analog or digital) and generate significant output. MEMS acceleration sensors incorporate a sensor with signal conditioning circuitry and are manufactured together in a single chip, which is very low in cost and highly reliable. The intelligent tool system developed in this study includes an MEMS vibration sensor, a microcontroller circuit board with embedded software, a ZigBee module and a lithium battery to provide power to these devices.

Similar previous studies; Suprock, C. A. et al. (2008) have implemented a wireless transmission system in which high bandwidth data can be obtained from a torque and temperature sensor mounted within the milling head holder. This special milling head holder transmits milling tip temperature and torque (torque) data throughout the cutting process to a remote computer in a wireless environment. Çolak (2006), During PHD's work, the cutting tool wear occurred during the milling of hard materials was determined by the sensors placed on the CNC milling machine. The optimal cutting conditions for milling are determined by artificial intelligence algorithms such as fuzzy logic modeling and genetic programming. In the study of the wear processes of selected cutting tools selected for milling hard materials, wear characteristics of surface milling and rough milling were investigated. Wright et al. (2006), in their work, the placement of temperature sensors within the head of a milling cutter and the transfer of temperature data to a remote computer via a wireless system. Two RTDs (Resistive Temperature Detector) are used as the temperature sensitivity. The aim is to simultaneously measure the tip temperature of the cutting tool which can reach high temperatures. Nicholas (2007), designed a smart tool holder for the CNC workbench in the thesis study. The system has installed a strain gage bridge for torque measurement, a "K" type thermocouple for temperature measurement, and a DAQ card with a 2.4 GHz bluetooth module for transmitting data to a remote computer. The data received from the sensors are transmitted to a remote computer via the Bluetooth transmitter and are recorded here. Tsai et al. (1999), In order to estimate the surface roughness of the machined parts in the milling process, the vibrations generated during the cutting process were collected in a computer by recording with the help of vibration sensors and modeled by analyzing this data. With this model, surface roughness is estimated at 96% accuracy. Lee et al. (2001), they investigate the shear forces that occur during high-speed milling and the vibrations that occur during this time. The experimental data obtained were analyzed with a prepared program. As a result, they found that the vibrations generated during cutting were an effective parameter on the surface roughness. Ertekin et al. (2003), During the CNC milling operations in their work, the surface roughness of the workpiece under various working conditions is examined using the vibration sensor data. The sensor data is evaluated in the regression analysis and the model equation to arrive at the surface roughness in the most accurate way is obtained.

With the technology developed in this study, high-cost counter-condition monitoring systems, which are currently used only by universities, research institutes, and research and development departments of major manufacturers, can be more attractive practical and achievable. Especially in CNC technology, the spread of complex machining tools will enable sensor data to be received at points that the current system can not reach. For example, when a part of a turbine blade being machined in a CNC machine running on a 7-axis is machined with a long finger mill, it is almost impossible to obtain vibration signals with the existing laser and piezo sensor data. The tingling effect that the vibration can generate in the processing of this part can only be monitored with a vibration signal which can be taken from within the tool. Since the damage that the rattle will give on the part is undesired, the measures to be taken according to the signals to be received by the MEMS micro sensors inside the tool will increase the quality of the processing. Such applications are particularly important in terms of ensuring and monitoring the precision of parts in the aviation and medical sectors. Sometimes in this sector the economic value of the parts processed is even higher than the CNCs that produce it, so there is no chance of making mistakes at the time of processing. This means that continuous monitoring and control of the machining situation is desirable. However, due to the high price of existing monitoring systems in the sector, investing in monitoring is avoided. Making advanced monitoring systems available to the industry can provide significant contributions in terms of cost of production, product quality, quantity of products, milling machine stability, tool selection and analysis of cutting parameters. Productivity and precision in production depend on a good monitoring system. For this reason, with the use of the "intelligent tool system;

- Precise milling of high cost materials,
- Preventing material faults by preventing errors in manufacturing process,
- Ensuring energy efficiency in production,
- It is thought to be beneficial in the development of safe processing techniques in machining.

With the developed intelligent tool system; it has been shown that it is possible to develop an easy-to-use and economical measuring system that can ensure that precautions are taken before faults occur in machining operations. It will be possible to track the position of the tool from the tool point at whichever axis, especially the dynamic analysis of the long sets with aerospace specification, and to minimize the material losses using smart processing technologies during machining. Zigbee and so on are not affected by noise in systems for monitoring and transferring data in machining, low power consumption and low cost. wireless data transmission systems have been shown to be able to run smoothly. The fact that MEMS sensors are in miniature size (5mm x 5mm x 2mm), low cost and high precision provide advantages for such systems. Thanks to this system it is proven that rotating parts can receive data from desired point by using various sensors. The simultaneous transfer of data to a computer allows data analysis either during or after data transfer. This intelligent tooling system is thought to contribute to the industry by allowing simultaneous monitoring of the problems occurring at the milling surface machining. It is also believed that the use of this system in the manufacturing industry will be useful in identifying the problems that occur during manufacturing and suggesting solutions for improving the production process.

2. Materials ve Methods

2.1. MEMS Based Sensors

In the past 30 years, it has been seen that millions of transistors resulting from large improvements in semiconductor electronics can be realized in the same integrated circuit. Thanks to these developments, miniature states of the mechanical and electronic systems that exist today are realized in micron dimensions on the same chip (Roco, 2001). Thus, the system price and dimensions can be as cheap and small as the chip. This technology is called Micro-Electro-Mechanical Systems or MEMS in short (Erkmen, 2004). There are many benefits of shrinking a mechanical system to a micro-scale. First, in such a system, the forces associated with volume (weight / inertia) lose their importance. As a natural consequence, very fast mechanical systems can be realized in the micro-scale world. Thus, it is possible to imagine many systems, from the instantaneous moving and stopping mechanisms to the sensors which can withstand very large acceleration movements. Micro-mechanical systems take up less space and expend less power than large-scale machine systems. With proper mass production techniques, it is an important fact that the production costs of such systems are very low (Güler, 2007). MEMS devices also have advantages such as being able to be manufactured with existing integrated processes, and to be designed with electronic circuits (Beeby et al., 2004). Today, thanks to MEMS, the cost of integrated accelerometers and electronics on single chips is less than $ 10 (Erbay et al., 2006).

One of the sensors that have become very important due to the development of MEMS technology is the acceleration sensor. Accelerometers are sensors that convert acceleration from static motion or static gravity into electrical signals (analog or digital) and generate significant output (Dölen & Kaplan, 2002). It generates an electrical output voltage proportional to the value of the oscillator. Acceleration occurs when a change occurs in the direction of the object or in the direction in which the velocity is directed. An acceleration sensor is also used to measure variable states such as impact, vibration, rotation, and slope (Erol & Serhatlıoğlu, 2011). Acceleration sensors have different operating methods. Some acceleration sensors use pieozoelectric effect. The microscopic crystal structures they contain are stretched with an accelerating force; which allows the voltage to be generated. Another way is to perceive the change on the floor. There are two types of acceleration sensors, analogue and digital. Accelerometers with analogue outputs produce a continuously varying voltage depending on the applied acceleration. In digital output acceleration sensors, a variable frequency square wave, known as PWM (pulse width modulation), is produced as the output signal (Kadıoğlu & Dinçer, 2008). Acceleration sensors are capable of measuring one, two and three axes separately or together (Dölen & Kaplan, 2004).

2.1.1. Adxl 78 MEMS Accelerometer

In order to obtain a better quality product in the machining and maximize the performance of the machine, the machining situation and performance can be monitored with the sensors placed on the machine during the process. Sensors with different characteristics are preferred for various purposes. Sensor based machining and monitoring is now seen almost everywhere in the manufacturing industry. Sensors, signal generators and data acquisition systems that have evolved with the development of digital technology have facilitated the evaluation of signals with algorithms developed through powerful computers. The production speed and quality for the same system are increasing day by day(Çolak, 2006).

The ADXL 78 model MEMS based acceleration sensor manufactured by Anolog Devices Inc. was used for the development of the intelligent tool system in the study. In Figure 1, the ADXL 78 (Ad22279) sensor is a MEMS-based sensor that performs analogue measurement on the x axis.

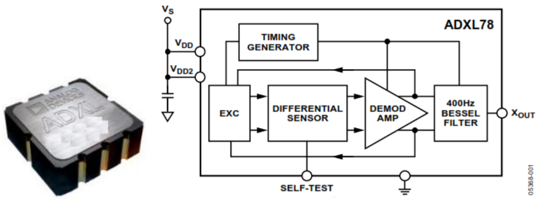

Figure 1. ADXL 78 MEMS sensor block diagram (ADXL 78 Data sheet, 2019).

MEMS based on accelerometers are preferred over traditional macro scale accelerometers because they are smaller, more functional, lighter and more reliable, and cheaper in price. Measuring both dynamic acceleration (vibration) and static acceleration (gravity), this sensor can measure up to ± 37 g. The ADXL 78 has a 5mm × 5mm × 2mm size, working from 3.5V to 6V. This work is powered by a 3.7V lithium battery (DC). The operating current of the accelerometer is also a small value of 1.3 mA, which keeps power consumption at low levels. With this feature, the intelligent tool system is able to work on the system for a long time and ensures that the measurements are made in sufficient time intervals. The ADXL 78 is an 8-axis acceleration sensor and is in the circuit. The output voltage varies directly with the supply voltage. The output sensitivity is 55mV / g for Vs = 5V. When the supply voltage increases, the noise sensitivity decreases. This is why the output sensitivity increases when the noise voltage remains constant.

2.1.2. ZigBee

The ZigBee name was taken from the zig-zag road that the bears watched as they roamed the flower from the flower. During this circulation, they act with the knowledge that other bees have reached these sources (from where they came from). As a new standard for wireless connectivity, ZigBee is based on the IEEE 802.15.4 standard announced by IEEE. ZigBee ensures the first general standard to be used in practice (Nagar & Biagioni, 2002). Considering the advantages of reliability, low cost and energy saving, ZigBee can be used in wireless connections of sensors and management products such as PC input devices. ZigBee allows automatic searching for wireless channels and the possibility of multiple wireless networks coexisting (Pinedo & Garcia, 2008). The distance to objects varies between 10 and 75 meters depending on the transmission power and environmental effects. Compared to other wireless technologies, this distance is both very long and requires very low power (Ercan, 2010). Depending on the flow of data, ZigBee devices dive deeply, saving energy (Yüksel & Zaim, 2009) and they can actively communicate with 30-40 units at the same time (Callavey et al., 2002). ZigBee is developed for low data-processing speed sensors and control networks (Bayılmış et al., 2004). The ZigBee architecture is based on two academic and industrial organizations (IEEE and the ZigBee Alliance) with more detailed protocol content and universal definitions than other technologies. Therefore, it has emerged as an alternative choice for ZigBee wireless area networks where Bluetooth-like or better industrial configuration is awaited (Çetin, 2009). The low power and relatively long distance reach of the ZigBee standard is a very attractive option for wireless applications (Kahveci el al., 2004). The package sizes used in ZigBee technology are small and are sent at long intervals. Since acknowledgment messages are generated to check whether packets are being sent, there is no loss of data (Bayılmış vd., 2004). When the power of a ZigBee node is turned off, it is reopened and the operation time is around 15ms (Ergen, 2004).

ZigBee is based on the strong radio (physical layer, PHY) and Medium Attachment Control (MAC) layers defined by the IEEE 802.15.4 standard. Media access is based on "contention". An IEEE 802.15.4 (ZigBee) network requires at least one fully functional device as a network manager, but endpoint devices can be functionally reduced devices to reduce system cost. The IEEE 802.15.4 standard is a standard operating at very low power and can be fed with battery blocks. One advantage of the pilots is that they have removed the network noise from the center. Thus, measurements made independent of the power grid can be much more precise. This is very important in industrial measurements. Less power consumption brings the physical dimensions of the machine to shrink. In parallel with this shrinking, the costs are reduced and thus the application areas of the electronic circuits are increasing (Ertürk, 2009). In this study, XBEE-XB24-BWIT ZigBee module is used (Figure 2).

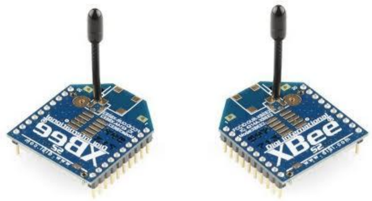

Figure 2. ZigBee XB24-BWIT Modül

These modules enable low-cost wireless data transmission using the ZigBee protocol, provide reliable data exchange between remote devices, and operate in the 2.4 GHz ISM frequency band.

2.3. The CNC Machine, the Workpiece and the Tool Used in the Tests

The final tests of the work were carried out at hartford vmc 1020 CNC milling machine at Süleyman Demirel University Cad / Cam research and application center (Figure 3).

Figure 3. Hartford VMC 1020 CNC

CNC milling machine is 4 axis. The worktable moves vertically on the z axis as the table top moves horizontally at the x and y axes. The table top dimensions are 1020mm on the x-axis and 500mm on the y-axis. The machine capacity is limited to 20 tool bindings. The maximum rotation speed of the work shaft is 6000 rpm. The workpiece used in this study (Figure 4) is Titanium (Ti-6Al-4V), a material widely used in aerospace and aerospace industries. The Ti-6Al-4V alloy reacts chemically with all cutting tools during machining.

Figure 4. Ti6Al4V workpiece

Ti6Al4V workpiece; Table 1 shows the mechanical properties and chemical composition (%) (Che-Haron & Jawaid, 2005).

Table 1. Mechanical properties and chemical composition (%) of Ti6Al4V alloy.

Mechanical properties			**Chemical composition**						
Tensile Strength (N/mm2)	Flow Strength (N/mm^2)	Elongation(%)	N	C	H	Fe	O	Al	V
900-1100	830	10	0.05	0.08	0.015	0.40	0.20	5.50	3.50

As the cutting tool, the tip of Seco 30179 ((Ti, Al) N-TiN) coated R217.21-1.00-0-R1252HA (Figure 5) was used.

Part No.	Dimensions in Inch									lbs		Type of mounting	Insert
	D_c	D_{c2}	dm_m	l_1	l_2	l_p	M	a_p					
R217.21 -0.625-0-R080.2	.36	.625	.625	1.00	6.0	3.5	-	.023	2	.18	53400	Cylindrical	218.19-080..
-0.75-0-R100.2	.41	.750	.750	1.25	6.5	4.0	-	.027	2	.30	32600	Cylindrical	218.19-100..
-1.00-0-R100.3	.66	1.00	1.00	1.50	7.0	4.5	-	.027	3	.60	29100	Cylindrical	218.19-100..
R217.21 -0.62508RER080.2	.36	.625	-	1.60	-	-	M08	.023	2	.06	53400	Combimaster	218.19-080..
-0.7510RER100.2A	.41	.750	-	1.84	-	-	M10	.027	2	.10	32600	Combimaster	218.19-100..
-1.0012RER100.3A	.66	1.00	-	2.25	-	-	M12	.027	3	.22	29100	Combimaster	218.19-100..
-1.2516RER125.2A	.81	1.25	-	2.50	-	-	M16	.039	2	.40	19700	Combimaster	218.19-125..
-1.2516RER125.3A	.81	1.25	-	2.50	-	-	M16	.039	3	.40	19700	Combimaster	218.19-125..
-1.5016RER125.4A	1.06	1.50	-	2.50	-	-	M16	.039	4	.40	17600	Combimaster	218.19-125..

Figure 5. Tool used in tests and features.

The copy milling tool is connected to the tool holder Seco Easy Shrink 15 machine. Figure 6 shows the mounting of the tool holder by thermal method (tight fit) of the cutting tools.

Figure 6. Placement of the tool holder by tight fitting of cutting tools.

3. Research Results and Discussion

In this work, a smart tool system has been developed in which the sensors, data processing and transmission systems are used in the simultaneous monitoring of the vibrations in the tool holder head for use in the milling process. This system may be used in simultaneous monitoring of vibrations occurring at the tip of the cutting tool during milling, and the effects of the mechanical vibrations occurring on the cutting tool on the surface quality may be determined. Developed intelligent tool system; In the MEMS structure, a vibration sensor, a microcontroller with embedded software, a circuit board (miniature card) containing a ZigBee transmitter module and a lithium battery to provide the power of these devices are installed. The energy consumption, dimensions and weights of all selected devices for the intelligent system are small.

3.1. Intelligent Team System Design

The system design was drawn in CAD environment and a data transmission system (miniature card) consisting of microcontroller circuit, sensor and ZigBee modules was created. The entire electronic wireless transmitter and receiver circuit design is made in a miniature size on a single printed circuit board (PCB) for the mechanical shell mount, with appropriate mechanical mountings (Fig 7).

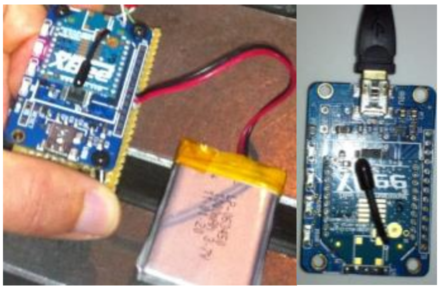

Figure 7. Developed miniature card and ZigBee receiver modüle.

The PIC 18F2550 microcontroller, which can provide 10 bit (capture and comparison 16 bit) resolution on the developed card, is used for collecting and digitizing the vibration data generated by the ADXL 78 MEMS vibration sensor placed on the tool holder head cap. Embedded software loaded into the microcontroller was compiled in the MPLAB IDE program using the C programming language. The microcontroller is the heart of the circuit in its entirety due to its features such as the conversion of analog signals from the sensor to digital, the processing of the converted signals to ZigBee mode. The microcontroller is programmed for this purpose. The microcontroller circuit operates with 3.7V DC voltage. This voltage is provided by a 3.7V Li-ion rechargeable battery. A ZigBee transmitter with a 2.4 GHz bandwidth was used for wireless transmission of the data, and this transmitter was connected to the microcontroller output for data transmission. The reception of the wirelessly transmitted data is provided by the ZigBee receiver module connected to the USB port of the computer. Data transfer is done by USB port. Numerical information is transferred as single axis (x axis) information. Digitally generated graphics are created simultaneously with desktop software developed, and simultaneously recorded in memory. Analysis can be performed on the recorded data (FFT, RMS, etc.) after the manufacturing process (Figure 8).

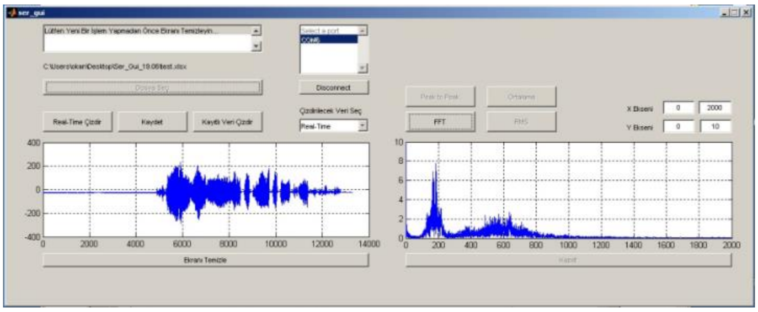

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Figure 8. Developed desktop software interface.

The developed system can analyze the surface roughness of the formed Ti6Al4V superalloy by monitoring the tool vibrations during the milling of the surface. The MEMS acceleration sensor is used as an acceleration sensor that measures the accelerations that occur in the applied force result. They are characterized by output voltage. It has advantages such as small size, high precision and low cost. The sensitivity of the sensor is applied in mV / g at the Vo pin, where the output voltage change per unit of g of applied vibration is determined. The output voltage (V_o) of the sensor, the vibration input (g) and the power supply voltage (V_s) are given in Equation 1. Where S is sensitivity, g is input acceleration.

$$V_o = \frac{V_S}{2-\left(\frac{S\times g\times V_S}{5V}\right)} \tag{1}$$

The results obtained show that the developed device has the ability to measure vibrations in response to acceleration changes of the acceleration sensor. In order to place the developed devices on the tool holder cap, a plastic rapid prototype was manufactured (Figure 9) and tightened onto the shaft.

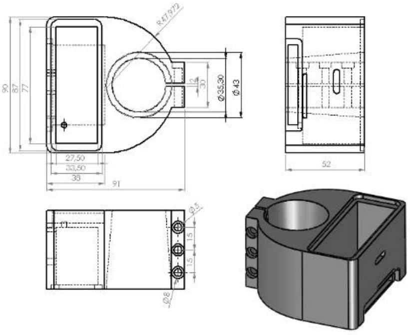

Figure 9. Developed plastic prototype and dimensions.

The developed software includes a microcontroller circuit board, a configured ZigBee transmitter module, and a 3.7V li-on battery to power these devices in the special compartments made in this prototype. Thus, a "Smart Tool System" was manufactured (Figure 10). In MEMS construction, a hole is made in the sensor dimensions on the insert for the vibration sensor and the sensor is placed in this hole. The connection between this sensor and the miniature card with ZigBee transmitter module developed in the scope of work is provided by inserting the special wire through the tool holder shaft. A MEMS sensor positioned on the cutting insert; high temperature formed at the cutting edge during the machining operation and the shield is coated with special putty resistant to heat to prevent it from being hit by hot sawdust.

The vibrations on the cutting tool were detected by the MEMS sensor and inspected by the microcontroller and the ISM was sent to a remote computer at 2.4 GHz frequency with the miniature card with the ZigBee transmitter module located inside the header. The data received from the computer connected to the ZigBee receiver module connected via USB port was stored in software in the MATLAB program and the frequency (Hz) - displacement (mm) graphs were obtained. In this view, the data received from the

MEMS vibration sensor placed in the toolholder head can be wirelessly sent to the computer via the developed miniature card. The Smart System block diagram, consisting of the single axis MEMS acceleration sensor, microcontroller and ZigBee transceiver module, is shown in Figure 10.

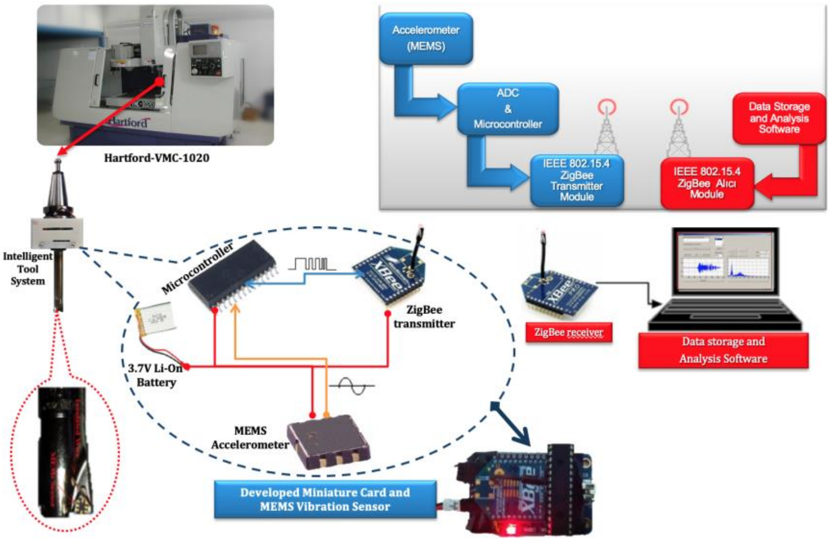

Figure 10. Intelligent Tool System Block Diagram.

The data from the sensitivities were used to simulate the dynamic cutting conditions and to evaluate the analysis results. The developed intelligent tool system test time is shown in Figure11

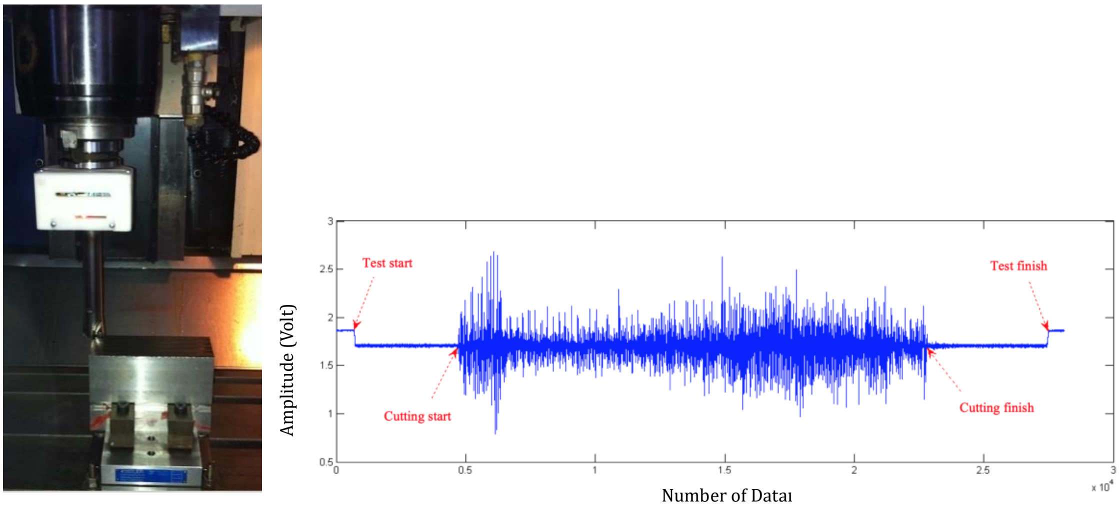

Figure 11. Sample vibration signal taken with intelligent tool system at the time of test.

Intelligent tool system; In the case of rotating devices, it is advantageous to transmit data received in real-time wirelessly with sensors from areas that are almost impossible to monitor with wired sensors to the computer, enabling data analysis both during and after data transfer.

3.2. Calibration

The calibration was done to test the accuracy of the data from the tool holder head where the MEMS sensor was attached. To perform the required calibration analysis, a hammer test was performed by attaching a PCB 353B31 piezoelectric sensor, which is reliable and calibrated to MEMS and measurement to the milling cutter tip (Figure 12).

Figure 12. Calibration

Statistics such as mean and standard deviation were applied to define the distribution of study data. The model equation was constructed using linear regression analysis for calibration. Two difference test (t-test) was used to compare the estimated value obtained from two different equations and the value obtained from the sensor. The data were analyzed with SPSS and the analysis results were tested with $\alpha = 0.05$ error margin. The experiment was carried out in two separate stages. In order to achieve the calibration, 11 strokes were performed with hammer aid in the first stage and data were collected from two sensors. To ensure that the data analysis is evaluated on the same unit, the units of measurement data of the two sensors are converted to volts. Data from transformed and different two sensors were evaluated using linear regression analysis. According to this analysis, the compliance ratio between the two sensors was 73% ($R^2 = 0.732$) ($p = 0.001$). In equation 2, the model equation is obtained. R; is the coefficient expressing the suitability of the regression equation. Depending on the relationship between dependent and independent variables used in each discipline or model, the acceptable value of R2 is the closest to the optimal value of 1, with varying values. As R^2 approaches 1; it is accepted that the regression model expressing the relationship between dependent and independent variables increases statistically close to the real relationship. According to Pearson coefficient; R^2 is 0.80 and above; is regarded as a strong relationship, and between 50% and 75% is regarded as a middle level relationship. In this case, when the modeled statistical regressions (Table 5) are examined, it appears that they are within acceptable limits.

Table 5. Model summary and parameter estimation

Dependent Variable: Piezoelectric Sensor							
Equation	**Model Summary**					**Parameter Estimation**	
	R Square	F	df1	df2	p values	Constant	Coefficient
Linear	0.732	24.582	1	9	0.001	-4.442	3.007

İndepended variable: MEMsSensor.

The model used to calibrate the compatibility between these two sensors is shown in Equation 2;

$$y = -4.442 + 3.007x \qquad (2)$$

In the equation (2) "y" is the expected value measured by the sensor PCB 353B31 and "x" is the value measured by the MEMS sensor. A separate 10-beat experiment was conducted to test the validity of the model. Measurements obtained from this experiment were converted to volts. The data from the MEMS sensor was substituted in equation 2 and the results were compared to the PCB 353B31 sensor measurement. Statistical correspondence of the data obtained from the MEMS sensor and the data obtained from the PCB 353B31 sensor with the transformed data was found by the t test (table 6,7) (p = 0.603).

Table 6. T-test result table

	t-testi						
	t	df	p value	Averege for Difference	Averege for Std. Difference	95% Confidence Range of Difference	
						Alt	Üst
MEMS	-0.530	18	0.603	-0.22181	0.41880	-1.10167	0.65805

Table 7. Destriptor table

Instruments	**N**	**Average**	**Std. Deviation**	**Std. Error**
MEMS	10	2.9548	0.82690	0.26149
PCB 353B31	10	3.1766	1.03448	0.32713

The result is that the model equation is suitable for calibration. The confidence interval is shown in Fig.16

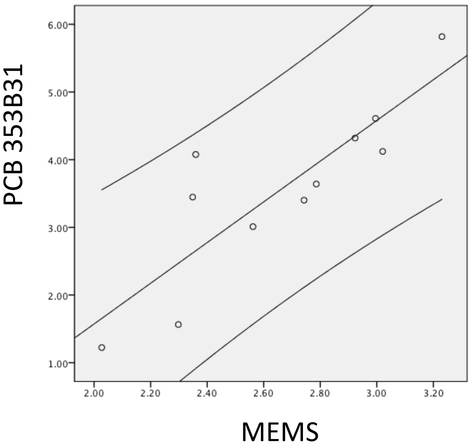

Figure 16. Confidence Interval Results

4. Conclusions and Recommendations

The most important factor to be considered in the manufacturing process is that the production is carried out in accordance with the highest quality and standards at the lowest cost. The development of machining, the increasing speed of cutting and advancing, the use of different materials in production and the development of machining benches are necessitating the use of condition detection systems in the machining industry. State detection methods that can be used in many different scenarios are based on the real-time implementation of decision-making algorithms for the current situation, which can be observed continuously instead of periodic maintenance performed at specific time intervals. In the machining of titanium (Ti6Al4V) materials covered in the study, the failure to make the manufacturing with sufficient precision at high speeds causes some mechanical problems and material loss on the material. This situation leads to the loss of time and money as well as the reason that this material with high economic value comes to the idle state. In this study, it is aimed to monitor the working conditions of the lathe by using wireless data transmission technology during the milling of titanium (Ti6Al4V) materials with the developed intelligent tool system. It is aimed to identify the problems encountered during manufacturing and to improve the production process. Simultaneous monitoring of vibrations in the tool holders on the machined surfaces with wireless communication as an innovative technology enables the acquisition of analysis information for immediate detection and resolution of some physical problems that may occur on the workpiece. It is thought that the obtained vibration data can be useful for precise milling of high cost materials by analyzing the surface roughness and machining stability of the formed parts, preventing material loss by preventing errors in the manufacturing process, ensuring energy consumption efficiency in production and suggesting solutions for developing safe machining techniques in chip production. With the developed intelligent tool system; an easy-to-use and economical measuring system has been achieved which can ensure that precautions are taken before machining errors occur in the machining operations. Thanks to this system it has been proven that the rotating parts can receive data from desired points by using various sensors. The fact that the MEMS sensor's circuits are in one piece, 5mm x 5mm x 2mm, offers the advantages of low cost and high precision measurement capability. Zigbee technology used in the system is not affected by noise, low power consumption and low cost because of features such as wireless data transmission during milling can be seen to work without problems. Monitoring and control possibilities in wireless communication systems, trouble-free operation with sensors and low cost indicate that the use of wireless data communication technology will be preferred. The system's small size, low cost of production, low power consumption and especially the ability to attach to rotating devices, as well as data transmission in real time on a computer in a wireless manner, during data transfer or after data analysis is important. It is thought that this intelligent tooling system will contribute to the literature by allowing simultaneous monitoring of the problems occurring at the milling surface machining. In this study, the temperature value at the time of cutting was not measured. In future work, the measurement of temperature values at the time of cutting can be done using inexpensive temperature sensors. In addition, the network property of wireless ZigBee technology can be used to investigate the effect of the magnetic field on the system, which can occur during the rotation of the intelligent tool system and the detection of the situation from one point to another (sensors, vibration, temperature, force).

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