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Development Of 3 Axis Force Measurement Systems for Machine Tools

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ABSTRACT

Force measurement systems are used in machine tools to determine the forces generated during machining. Optionally available force measurement systems have a considerable cost. In this study, a model capable of measuring force in 3 axes with 2 N measurement accuracy has been developed. The measurement system developed in the study gives effective results in the range of 0-1ton defined by a Labview based algorithm. The system calibrated according to ASTM E74-13 has produced successful results in metal forming operations. At the end of the study, suggestions were made to improve the efficiency of the system.

INTRODUCTION

Various forces occur in production operations such as metal forming and chip removal. The measurement and evaluation of these forces are of great importance in R&D studies. Therefore, many processes require a multi-axis force measurement system. Today, various force measurement systems are available as an option on the machine tool. But, the sales prices of these systems are quite high. The prices of these products are unacceptable for design or prototype development processes with low production potential. In this case, many researchers and enterprises are forced to continue the project work without force measurement.

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Gibson at al. developed a low-cost force measurement system (Gibson et al., 2012). Wan et al. validated a table-type dynamometer for measuring shear force (Wan et al., 2016). Hsieh et al. developed a dynamic calibration tool for force platforms (Hsieh et al., 2011). Yang et al. developed a system for measuring the gripping force of a gripper using a gas pressure sensor (Yang et al., 2017). Guaus et al. have developed a method for calibrating the force sensor used to adjust the tension of the violin wire (Guaus et al., 2009). Bayrakçeken and Altıparmak developed test equipment to measure the braking forces in passenger vehicles and calibrated the device (Bayrakçeken & Altıparmak, 2007). Silva et al. have developed an inexpensive force measurement system that measures force and stores measurement data on a computer (Silva et al., 2017). Schlegel et al. have developed a dynamic calibration method for force transducers with sinusoidal output [8]. Klocke et al. investigated new force measurement methods used in aviation (Klocke et al., 2015). Uzun and Korkut have made the design and manufacture of the experiment set for drilling and milling processes to measure the cutting forces (Uzun & Korkut, 2011). Ruiz et al. demonstrated piezoresponse forces using non-conductive materials (Flores-ruiz et al., 2017). Heydarzadeh et al. estimated shear force using neural networks (Heydarzadeh et al., 2018). Liu et al. developed a triaxial force measuring device placed on the sole of the shoe (Liu et al., 2012). Lader and Enerhaug measured lift forces using different loadcells (Lader & Enerhaug, 2005). Liang et al. developed a triaxial force measurement system using flexible capacitive tactile sensors (Liang et al., 2015). Demir et al. developed a dynamometer for measuring grinding forces in plane grinding (Demir et al., 2006). Kaçal et al. developed a cutting force measurement system for the hobbing gear wheel manufacturing process (Kaçal et al., 2008).

When the studies in the literature are evaluated, it is seen that the operational capabilities of this study are more effective. In particular, it can respond to many different applications and has a wider measuring range. In this study, a 3-axis force measurement system has been developed with a very low budget. In the developed system, a design was made using 3 different load cells and its production was realized. In this context, the design and construction of the model were explained, and calibration studies were performed to determine the measurement accuracy of the system.

DESIGN AND CONSTRUCTION

3 load cells were used in the force measurement system. Baykon BT604 load cell (S type) was used for X and Y axes (*BT604 Catalog*, 2009). Baykon BP320 load cell was used for the Z-axis (*BP320 Catalog*, 2016). All load cells have one-ton capacity. The load cell used in the X and Y axes (Baykon BT604) can operate in both pull and push direction. The load cell used in the Z direction (Baykon BP320) can only operate in the pressing direction. The used load cells are shown in

Fig. 1. The measurement accuracy of all three loadcells is 2 N. With the arrangement of the strain gauges in the Baykon BP320 used on the Z-axis, the momentum effect is zero in an area of 800 mm x 800 mm (*BP320 Catalog*, 2016). This feature is provided by the loadcell manufacturer with the array of strain gauges in the load cell. The moment effect can be eliminated when the force applied during operation remains within this area. The vertical load is measured accurately wherever the force is within this area.

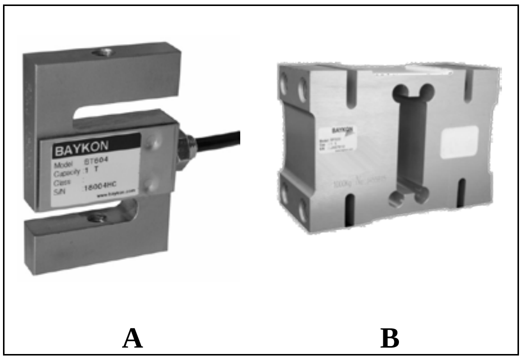

Fig. 1. Loadcells. A) BT604 B) BP320

Mechanical design was done using the SolidWorks program. Linear guides are used in the X and Y axes for accurate measurement of forces not parallel to the X or Y-axis. First, all parts were drawn on a 1:1 scale and then assembled in the design program. Overlap analysis was performed to verify the accuracy of the assembly (

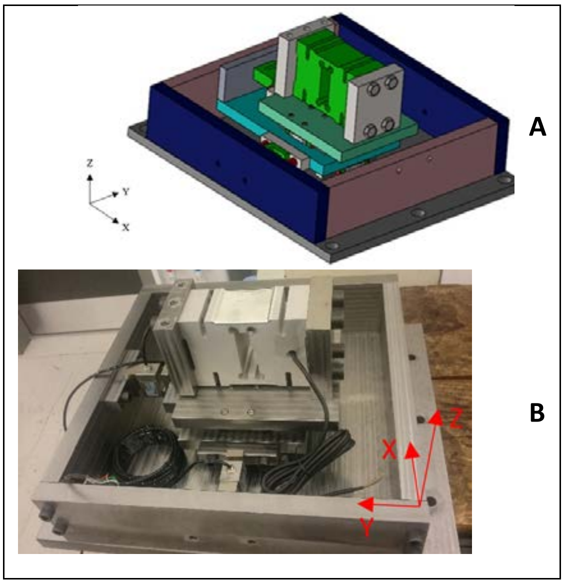

Fig. 2). Then the parts are machined on CNC milling machine and force measurement system is produced.

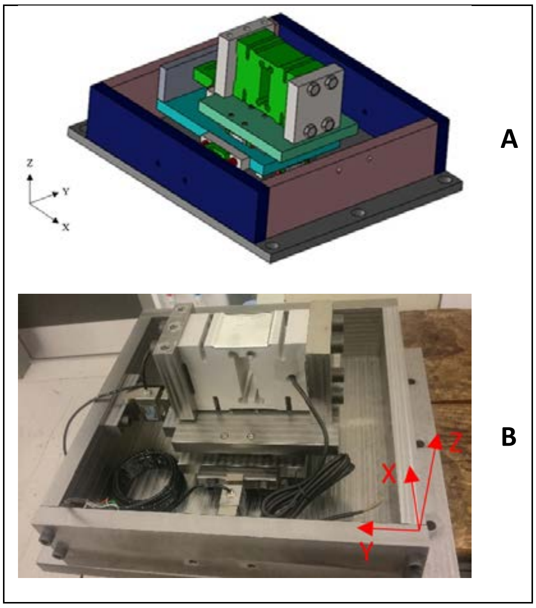

Fig. 2. Force measurement system. A: Design installation, B: Manufactured

After the mechanical assembly was completed, the electronic assembly phase was started. The signals received from each load cell are processed by transmitting them to individual transmitters (Baykon TX13) (*TX13 Weight Transmitter Technical Manual*, 2016). The transmitters process the millivolt output signal from the loadcell and output it as a 4-20 mA analog output. Current values from three TX13 transmitters are collected on the National Instruments USB-6003 data acquisition card (*NI USB-6003 Catalog*, 2014). The data acquisition card and the computer are connected via Universal Serial

Bus (USB) cable. Electronic installation is given in Fig. 3.

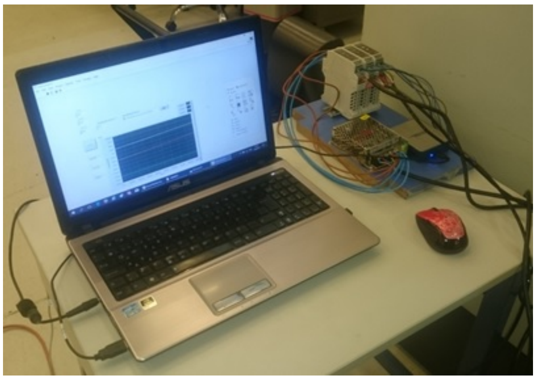

Fig. 3. Electronic installation.

An interface was prepared using the Labview 2017 program (Fig. 4). In this interface, load data from three different loadcells are visualized. In addition, the measured values are saved in the file with the extension *.tdms. The interface is user-friendly. The user enters the sampling frequency, conversion coefficient, and file recording path and starts the measurement. At the end of the measurement process, it stops the measurement by pressing the “stop” button. The block diagram of the force measurement system is given in Fig. 5.

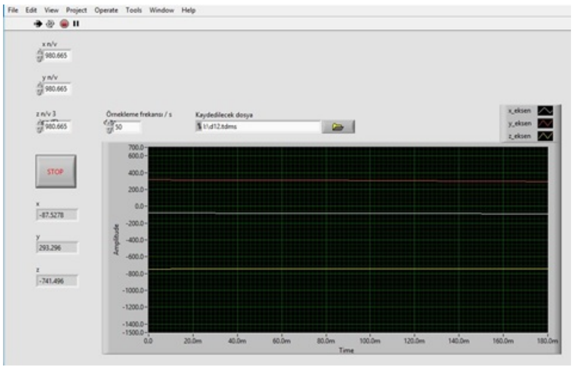

Fig. 4. Force measuring system interface.

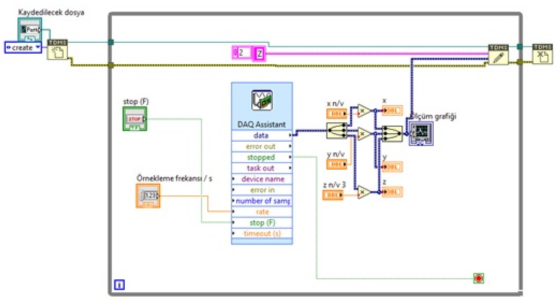

Fig. 5. Force measurement system block diagram.

CALIBRATION

Calibration studies were performed according to ASTM E74-13 (ASTM, 2013). Since all load cells have a capacity of 1 ton, a total weight of 100 kg was applied twice. The loads shown in Table 1 were then applied twice

(

Fig. 6). The load application was carried out from small to large in the order of Table 1. The forces (Newtons) measured twice were averaged.

Table 1. Loads used in experiments.

Load No	Applied Load (kg)
1. load	10.6
2. load	20.6
3. load	30.7
4. load	40.5
5. load	50.6
6. load	60.2
7. load	70.2
8. load	80.3
9. load	90.1
10. load	100.2

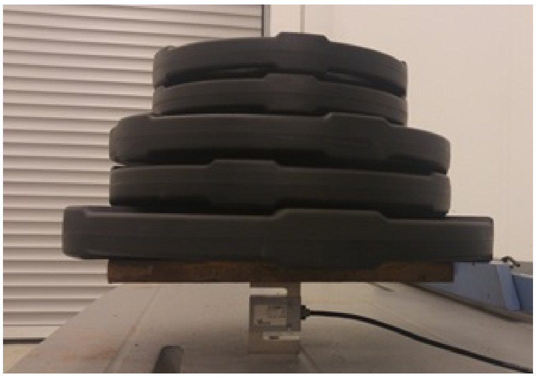

Fig. 6. Calibration studies.

In the Fig. 7, X-axis, in Fig. 8 Y-axis, in Fig. 9, Z-axis Load-Force graph is given. Linear regression analysis was performed for each graph. Regression (R^2) values in regression analysis:

For the X-axis: $R^2 = 0.99998797$

For the Y-axis: R^2 = 0.9999485
For the Z-axis: R^2 = 0.999997287
calculated as. These results show that the kg-N curves are almost linear. The fact that the regression coefficients are close to 1 indicates that the developed measurement system has high measurement accuracy, and it performs accurate measurements.

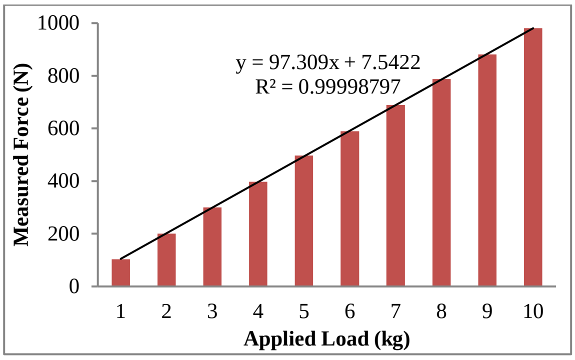

Fig. 7. X-axis measurement values (kg-Newton).

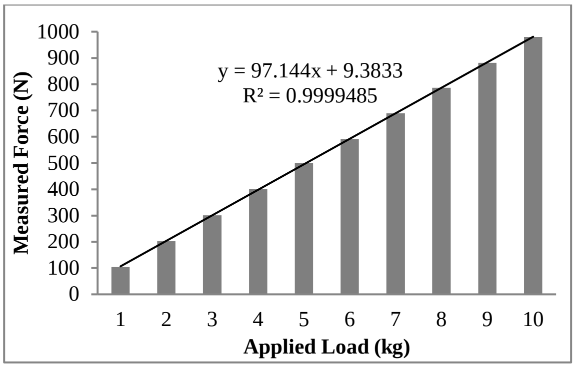

Fig. 8. Y-axis measurement values (kg-Newton)

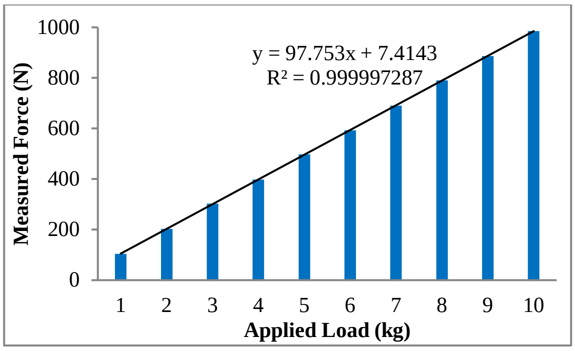

Fig. 9. Z-axis measurement values (kg-Newton)

After the sequential loading process was completed, the load cells were subjected to a constant load of 100.2 kg for 20 minutes to determine the measurement stability (Fig. 10). The force measurement data for all three axes for 20 minutes is shown in Fig. 11. No deviation was observed in the measurements. These findings show that the developed force measurement system is stable.

Fig. 10. 20-minute measurement experiment for the Z-axis.

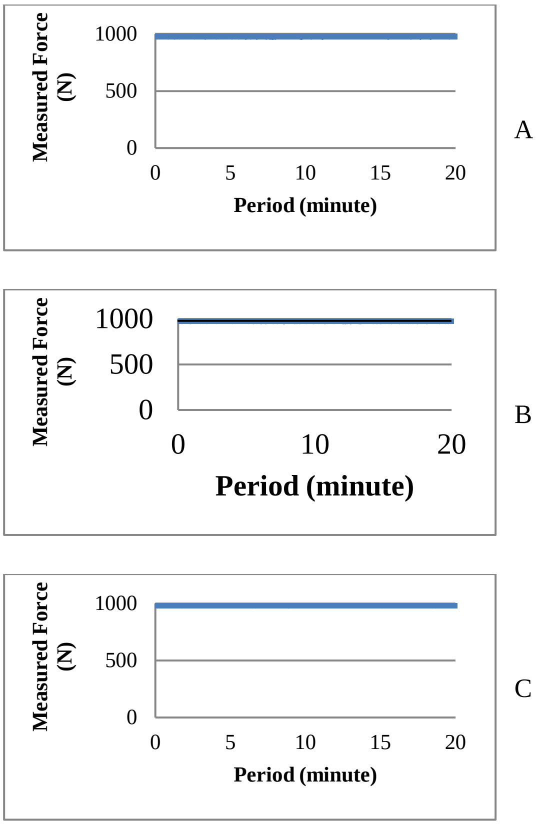

Fig. 11. Load application test results for 20 min. A) X-axis, B) Y-axis, C) Z-axis.

In addition to the single axis tests, loads were applied simultaneously in 3 axes. Stable measurements were also taken in simultaneous loading (Fig. 12). In Fig. 13, using of force measuring system on CNC machining center is shown.

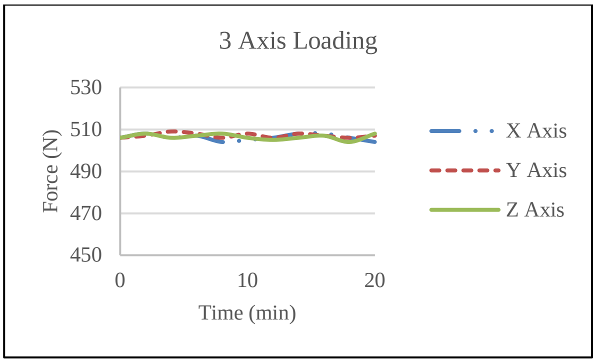

Fig. 12. 3 axis load application test results for 20 min.

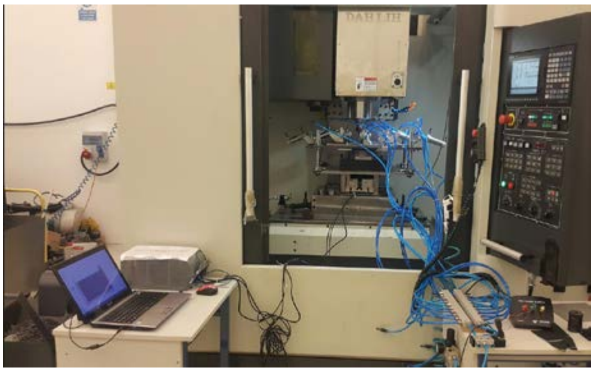

Fig. 13. Using of force measuring system on CNC machining center.

CONCLUSION

In this study, a force measurement system has been developed which can measure force on three axes and record it to the computer. This system is manufactured with a very low budget (about $ 4000). Calibration of the developed system is done according to ASTM E74-13. The calibration curves (kg-N) for all three axes are almost linear. This shows that the measurement accuracy is quite high.

Loadcell used in the Z direction has been freed from the moment effect in the 800 mm x 800 mm area in the factory production stage. This allows the continuous force to be measured wherever the vertical force is located in this area. It is evaluated that the developed force measurement system can be used precisely in different processes such as chip removal, forming, friction welding by using a suitable work clamping mold.

As a continuation of this study, it is aimed to make the force measurement system suitable for working in an aqueous environment.

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