Development of Low-Cost Piezoelectric Tool Force Dynamometer

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Abstract - *This research article contains the entire development of low-cost piezoelectric tool force dynamometer to measure cutting force, feed force & thrust force. There are multiple types of dynamometers available in the current market and they are really costly according to their individual application. In order to create cost-effective and efficient working piezoelectric dynamometer, we have studied multiple articles and journals of various reputed authors in the same field. We took upon the mantle and completed the setup, which is in detailed is explained the article. After that, we have tested our setup and experimented on the Lathe using various parameters like depth of cut, feed per revolution and cutting speed and as output we've received the above-mentioned forces. We've also compared the theoretical calculated forces and practical output forces and found out that it works efficiently with the error of just + 2.3%, which is quite under control. In conclusion we have created a budget friendly piezoelectric dynamometer, which could be used in useful in production industries as well as in engineering colleges for demonstration in order to understand the working and concept of the piezoelectric dynamometer.*

Key Words: **(Piezoelectric Dynamometer, Low-cost Dynamometer, Force Measurement, Lathe Dynamometer.**

1.INTRODUCTION

A dynamometer is a machine used to quantify force and rotational speed (rpm) from which force delivered by a motor, engine, siphon or other pivoting central player can be determined. To put the investigation of the metal cutting procedure on a subjective premise, certain perceptions should be made previously, during and after a cut. A dynamometer that is intended to be driven is called a retention or detached dynamometer. A dynamometer that can either drive or assimilate is known as a universal or dynamic dynamometer. As well as being utilized to decide the force or force attributes of a machine under test, dynamometers are utilized in various different jobs. In standard outflows testing cycles, for example, those characterized by the US Environmental Protection Agency, dynamometers are utilized to give recreated street stacking of either the motor or full powertrain. Indeed, past basic force and force estimations, dynamometers can be utilized as a component of a test-bed for an assortment of motor advancement exercises. The piezoelectric dynamometer was synced with Arduino microcontroller. The tool holder was drafted in 3D modelling software. This piezoelectric circuit was designed to measure 30KN cutting force, thrust force and feed force on lathe during machining operation. The operating parameters were depth of cut, feed per revolution and cutting speed. The main objective of this research was to develop a working model of piezoelectric dynamometer and justify that it's safe fewer than 20N loading conditions.

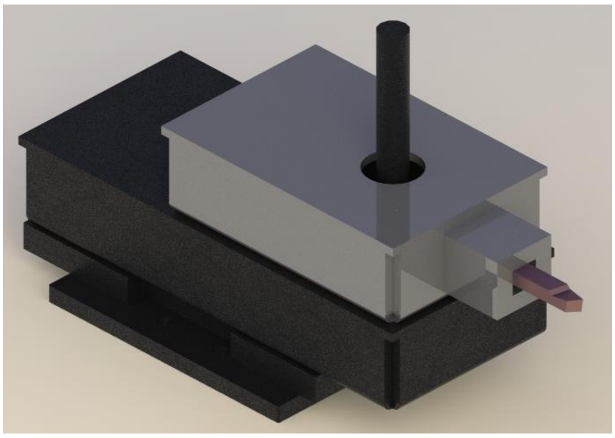

Fig. 1.Cad model of proposed dynamometer

2.LITERATURE REVIEW

Jullien et al. (2020) has Measured the high-recurrence processing powers utilizing piezoelectric dynamometers with dynamic pay. During the experimentation, the creator has referenced that the power reproduction was influenced by the variety of framework elements during processing just as the pay was accomplished utilizing Sliding Mode Observer, vigorous against framework changes. The sliding mode eyewitness was contrasted and the Kalman channel and de-convolution. In the end, the Sliding Mode Observer has ensured no yield assessment mistake in limited time **[1].** **Ren et al. (2019)** has done an exploration on the heap sharing guideline of a novel piezoelectric dynamometer. The scope of three-dimensional piezoelectric sensors in two digressive ways, contingent upon the most extreme static contact power produced by pivotal preload, is generally only one-fifth of the hub preload, or even lower. It enormously restricts the use of piezoelectric sensor in those circumstances where digressive estimating range was equivalent or bigger than hub estimating range. This article proposes a strategy that utilizations split round and hollow pins to acknowledge load sharing just unrelated way, and afterward builds up a heap sharing numerical model dependent on the range of barrel shaped pin. At last, Finite Element Method (FEM) was utilized to examine load-sharing strength of 10 mm round and hollow pin and split pin. A heap sharing investigation dependent on a three-dimensional piezoelectric dynamometer with an extraneous scope of 1kN and a hub scope of 5kN is planned. The exploratory outcomes show that the extraneous burden sharing proportions are 21.4% and 23.0%, the hub load-sharing proportion is 81.0%, which is concurring well with the consequences of FEM investigation. It demonstrates that the static estimation exactness of the piezoelectric dynamometer pivotal way isn't influenced. Incredible burden sharing execution digressive way however little burden sharing execution pivotal way can be acknowledged by utilizing split round and hollow pins **[2]. Lad et al. (2019)** has distributed the exploration article that managed the advancement of strain measure dynamometer. This arrangement was created to gauge cutting powers in machining activity. The cutting power can't be distinguished or measured straightforwardly however their impact can be detected utilizing Transducer. A power which nor be seen nor be held, yet can be identified and furthermore evaluated individually by its impact and the measure of those impacts like versatile avoidance, twisting, pressure, strain and so forth These impacts, called signals, regularly need legitimate molding for simple, exact and dependable identification and estimation. This arrangement is likewise increment effectiveness and exactness of power estimation by apparatus redirection in less time without forfeiting precision of the item. This strain check was intended to quantify 200 kg cutting power and feed power too. The working boundaries were profundity of cut, feed per unrest and cutting rate **[3]. Liang et al. (2016)** has created strategies and examination for multi-segment cutting power detecting gadgets and approaches in machining. During the examination, the creator expressed that the multi-part cutting power detecting frameworks in assembling measures applied to cutting apparatuses were bit by bit turning into the main observing marker. Their signs were widely applied to assess the machinability of work-piece materials, foresee shaper breakage, gauge cutting device wear, control machine instrument chat, decide stable machining boundaries, and improved surface completion. Hearty and powerful detecting frameworks with ability of checking the cutting power in machine tasks continuously are significant for understanding the maximum capacity of cutting capacities of CNC instruments. The principle objective of the examination was to introduce a concise survey of the current accomplishments in the field of multi-part cutting power detecting frameworks in present day fabricating **[4]. Rizal et al. (2015)** has done Development and testing of an incorporated pivoting dynamometer on instrument holder for processing measure. They've shown that the framework was fit for estimating the principle cutting power, the push power, and the opposite cutting power. Additionally, the sensor framework was a strain check dependent on the power detecting component that is prepared by inductive telemetry framework. The created dynamometer was portrayed through the investigations under static and dynamic stacking conditions. The outcomes show that the created dynamometer had high linearity, affectability, and unbending nature **[5]. Sharma et al. (2015)** had dissected the cutting powers of the machine apparatus dynamometer. In this examination, according to cutting investigation of powers, it has been inferred that the cutting and feed power was straightforwardly relative to profundity of cut and feed pace of hardware and conversely corresponding to take care of/fire up. Among with this examination, the scientists have considered different impacts of the boundaries affecting the estimation too and reasoned that the cutting powers are estimated by utilizing electrical strain measure is the best strategy Available **[6]. Panzera et al. (2012)** had done the advancement of a three-part dynamometer to quantify the turning power. The investigation was centered on the plan, development and testing of a strain check dynamometer concocted to gauge the three segments of the turning power. For this reason, a versatile component touchy to twist and flexion was created. The impact of the cutting boundaries (cutting rate, feed rate and profundity of cut) on the power segments was examined. Moreover, the exhibition of the dynamometer was contrasted and a business piezoelectric gadget. The outcomes demonstrated that the three parts of the turning power decline somewhat as cutting velocity was raised and increment directly with feed rate and profundity of cut. The investigation of difference showed that the three segments are not essentially influenced by cutting velocity; nonetheless, they are fundamentally influenced by feed rate and profundity of cut. The relative tests demonstrated that the strain measure dynamometer introduced an agreeable execution, giving nearer qualities to the piezoelectric dynamometer at higher profundity of cut qualities **[7]. Benmohammed et al. (2012)** has done the estimations of the cutting powers during irregular machining measure. The creator addressed the different situations where the estimation of cutting powers in quick brief mode was fundamental and furthermore uncovered a strategy for pay of inertial impacts which denatures the signs given by the most utilized piezoelectric dynamometers. The prospects of this technique, in view of the speed increases estimations of the upper piece of the dynamometer, were uncovered for the situation of a spasmodic turning measure. It was shown that the unfortunate impacts identified with the reverberation frequencies of the dynamometer and to their base developments were chiefly wiped out **[8]. Yaldız et al. (2007)** had decided the areas of strain check to acquire greatest yield of ring least cross-affectability under distortion. To gauge the unique cutting power, an accelerometer was appended to the dynamometer in estimation heading and the powerful cutting power figuring was additionally given. For information move between the dynamometer and PC, an appropriate exploratory set-up was performed and reasonable programming was composed. In face processing tasks, fitting outcomes were acquired in cutting power estimations. The regular recurrence of dynamometer in X, Y and Z headings fulfilled the vital inflexibility and dynamic reach. The outcomes acquired from the machining tests performed at various cutting boundaries showed that the dynamometer could be utilized dependably to gauge cutting powers in processing as well as in other machining measures as turning, pounding and forming measures **[9]. Karabay et al. (2007)** had talked about in minimal type of detail the essential plan standards of versatile individuals and conditions commonly utilized in plan. He saw that the cutting power estimation at apparatus condition checking have been discovered more precise as per vibration, acoustic mission temperature and force utilization estimation. What's more, such gadgets may likewise be utilized in versatile control adding proper electronic and PC equipment **[10]. Singh et al. (2006)** has planned and built up the Strain Gauge based Dynamometer for estimation of cutting power on a Lathe. The creator has considered the previous advancement in metal cutting advances and the yearning for additional improvement have expanded the significance of estimation of cutting powers at the plan of machine instruments and cutting apparatuses, installations, choice of cutting boundaries for ideal activity execution. Also, reasoned that to get the precise measure powers on the machine and to peruse the cutting power information naturally, the essential information procurement framework was planned and created with the fundamental equipment and programming conceived and associated with it **[11]. Yaldiz et al. (2006)** has proposed a dynamometer plan for estimation the cutting powers for explicitly turning activities. They have contemplated the cutting powers produced in metal cutting impact age heat, instrument wear or disappointment, nature of machined surface and precision of the work piece. In this investigation, a turning dynamometer that can quantify static and dynamic cutting powers by utilizing strain measure and piezo-electric accelerometer individually has been planned and built. The direction of octagonal rings and strain check areas has been resolved to expand affectability and to limit cross-affectability. The power signals were caught and prepared utilizing appropriate information securing framework. The dynamometer has been exposed to a progression of tests to decide its static and dynamic qualities. The outcomes acquired showed that the dynamometer could be utilized dependably to gauge static and dynamic cutting powers and furthermore reasoned that Dynamometer can quantify three opposite cutting power segments all the while during turning and the deliberate mathematical qualities can be put away in PC by information obtaining framework. It had been formulated and associated with important information securing framework comprising of equipment and programming. That dynamometer was intended to compare 3500 N most extreme power and the affectability of framework was ±5 N. The estimations of cross-affectability of the dynamometer for the three bearings were determined in the scope of 0.17–0.92%. Dynamometer can be expected really solid disregarded. In turning activities, proper outcomes were gotten in cutting power estimations. The acquired aftereffects of machining tests performed at various cutting boundaries shows that the dynamometer can be utilized dependably to gauge cutting powers. In spite of the fact that it was planned fundamentally for turning, it very well may be utilized for processing and penetrating also **[12]. Van et al. (2012)** has played out the alignment of dynamic piezoelectric power transducers utilizing the hopkinson bar method. Effect testing was an extending research territory in the mechanical climate just as in the scholastic field. Estimations during these powerful occasions were generally centered on securing the heaps which happen. This makes dynamic power sensors the main transducers during these effect tests. Sensors utilizing piezoelectric gems were entirely appropriate for recording dynamic loadings since the precious stones display an incredibly high common recurrence and have a fantastic direct conduct over a wide plenty fullness range. Notwithstanding, these power sensors were hard to adjust, since they can't obtain static burdens. A few alignment methods as of now exist for adjusting these sensors. Nonetheless, the greater part of them needs different sensors which are likewise hard to align, and regularly costly hardware was essential. This work presents another, genuinely simple and economical strategy for aligning unique piezoelectric power transducers, which didn't require different sensors hard to adjust. It utilized a split Hopkinson pressure bar arrangement in which the test example is supplanted by a unique power sensor. It was shown that the striker bar with its starting framework, which typically goes with the arrangement and was the costliest piece of the test rig, was on a fundamental level excessive for adjustment purposes. This empowers the development of an ease adjustment gadget when contrasted with other existing alignment methods. The power beats created in the arrangement can run up to 20 kN in greatness and rise seasons of 50 μs at the most limited can be accomplished **[13]. Akbar et al. (2019)** has examined the adjustment of piezoelectric dynamometer dependent on neural organizations. The examination addressed the adjustment techniques for power estimating piezoelectric dynamometer dependent on neural organizations. Preparing and test information for neural organization was acquired through tests. Two BP-calculations, Broyden-Fletcher-Goldfarb-Shanno (BFGS) - Quasi Newton calculation and Leven bergMarquardt (LM) calculation are utilized to adjust the dynamometer yields. At that point the proposed strategy was approved by looking at the yields of the two calculations. The outcomes demonstrate that LM calculation based prepared organization produces exact yield contrasted with the organization prepared with BFGS calculation **[14]. Tian et al. (2018)** has built up a novel alignment strategy dependent on kirchh-off hypothesis for piezoelectric dynamometer. The examination was expected to improve alignment and power estimation precision of multi-sensors' piezoelectric dynamometer utilized in push estimation of rocket/air vehicle motor. It additionally addressed a planning arrangement strategy for sensors' yields dependent on the Kirchhoff dainty plate hypothesis, assembles power deformity differential conditions with explicit limit conditions, utilizes limited contrast (FD) technique to tackle the conditions and investigates yields in balance stacking powers in four sensor square format primary way. The resultant power deviations determined by the Kirchhoff hypothesis are improved with grouping quadratic program (SQP) strategy, and an alignment technique for various stacking focuses (MLP) in view of the Kirchhoff hypothesis is introduced. Tests of static adjustment and confirmation are supplemented to differentiate the novel and single stacking point (SLP) alignment technique. Tests of static adjustment and its check show that at a stacking power of 5,000N, the normal resultant power deviations with MLP is 17.87N (0.35% FS) contrasted and single stacking point strategy 26.45N (0.53% FS), improving alignment and estimation accuracy [15].

3.REQUIRED COMPONENTS

This attachment which is used for measuring of cutting forces as well as feed forces while machining the work-piece as well as increasing the tool life. Components required for preparation of proposed project are listed as following:

A. Microcontroller

Arduino is a PC equipment and programming organization, venture, and client local area that plans and fabricates miniature regulator packs for building advanced gadgets and intelligent items that can detect and control objects in the actual world. The sheets are furnished with sets of advanced and simple info/yield (I/O) sticks that might be interfaced to different extension sheets (safeguards) and different circuits. The microcontrollers are ordinarily modified utilizing a vernacular of highlights from the programming dialects C and C++. As well as utilizing conventional compiler tool-chains, the Arduino project gives an incorporated improvement climate (IDE) in light of the Processing language project.

B. Tool

In a circumstance of machining, a cutting device is any apparatus that is utilized to eliminate material from the work-piece by methods for shear misshaping. Single-point instruments are utilized in turning, molding, arranging and comparable tasks, and eliminate material by methods for one bleeding edge. Processing and penetrating apparatuses are regularly multipoint devices. Pounding instruments are additionally multipoint apparatuses. Each grain of grating capacities was as a minute single-point forefront and shears a little chip. Cutting apparatuses should be made of a material harder than the material which is to be cut, and the instrument should have the option to withstand the warmth created in the metal-cutting cycle.

C. Piezoelectric Sensors

A piezoelectric sensor is a gadget that utilizes the piezoelectric impact to gauge changes in pressure, speed increase, temperature, strain, or power by changing them over to an electrical charge. The manner in which a piezoelectric material is cut characterizes one of its three primary operational modes: transverse impact, longitudinal impact & shear impact.

4. METHODOLOGY

The examination relies on procedure picked the procedure as it chooses the method of gathering the information, control, handling lastly the showcase of the outcomes:

1) Measurement of reducing power by utilizing low expense piezoelectric sort of dynamometer is the best method accessible.
2) The machining boundaries will be considered during the machining concerning cutting powers and feed powers by foreseeing the cutting exhibition like profundity of cut, feed/fire up. Furthermore, speed.
3) The normal recurrence of the instrument holder of machine device dynamometer will be determined.
4) Stress computation will be done for the protected plan of machine device dynamometer:

The general principle of measurement is displayed in the chart given below in Fig.2:

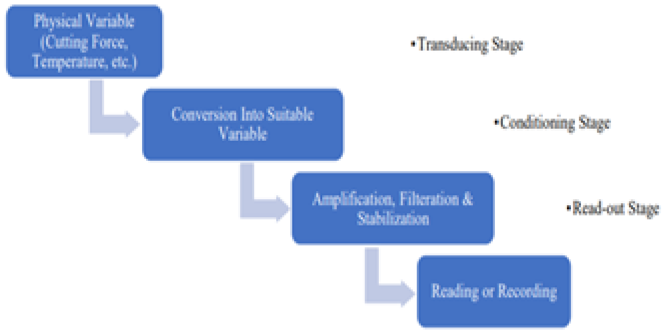

Fig. 2.Flow Chart of General principle of measurement [3]

5.PIEZOELECTRIC SENSOR DESIGN & SENSING MATERIALS

In light of piezoelectric innovation different actual amounts can be estimated the most well-known are pressing factor and speed increase. For pressure sensors, a slim film and a monstrous base is utilized, guaranteeing that an applied pressing factor explicitly stacks the components a single way. For accelerometers, a seismic mass is connected to the precious stone components. At the point when the accelerometer encounters a movement, the invariant seismic mass loads the components as per Newton's second law of movement F=m*a. The fundamental distinction in working guideline between these two cases is the manner in which they apply powers to the detecting components. In a pressing factor sensor, a slim film moves the power to the components, while in accelerometers an appended seismic mass applies the powers. Sensors frequently will in general be touchy to more than one actual amount. Pressing factor sensors show bogus sign when they are presented to vibrations. Modern pressing factor sensors hence use speed increase pay components notwithstanding the pressing factor detecting components. Via cautiously coordinating with those components, the speed increase signal (delivered from the pay component) is deducted from the joined sign of pressing factor and speed increase to determine the genuine pressing factor data. Vibration sensors can likewise reap in any case squandered energy from mechanical vibrations. This is refined by utilizing piezoelectric materials to change over mechanical strain into usable electrical energy. Three fundamental gatherings of materials are utilized for piezoelectric sensors: piezoelectric pottery, single gem materials and meager film piezoelectric materials. The ceramic materials have a piezoelectric steady/affectability that is around two significant degrees higher than those of the characteristic single gem materials and can be delivered by economical sintering measures. The piezo-impact in piezo-pottery is "prepared", so their high affectability corrupts after some time. This debasement is profoundly related with expanded temperature. The less-delicate, regular, single-gem materials (gallium phosphate, quartz, and tourmaline) have a higher – when deliberately dealt with, practically limitless – long haul security. There are likewise new single-gem materials monetarily accessible like Lead Magnesium Niobate-Lead Titanate. These materials offer improved affectability over PZT however a lower most extreme working temperature has and are right now more confounded to fabricate because of four compounds versus three compound materials PZT. Dainty film piezoelectric materials can be fabricated using faltering, substance fume testimony, nuclear layer epitaxial and techniques. Slim film piezoelectric materials are utilized in applications where high recurrence is used in the estimation strategy or potentially little size is supported in the application. The setup consists of tool box, additional tool holder, piezoelectric circuit and cutting tool. The additional tool holder is required in order to protect the circuit, which was soldered with the tool.

6.EXPERIMENTAL SETUP

The experimental setup of piezoelectric dynamometer in operational is shown in Fig. 3, while the force measurement circuit is shown in Fig. 4. The technical specifications of the components used in this setup are displayed in Table-I given below.

1) Dynamometer set over cross slide
2) Dynamometer fit by tool-post nut
3) Sensors assemble as shown in Fig.4 with help of rubber
4) Sensors and LCDS are directly connected with microcontroller

Fig. 3 Piezoelectric Dynamometer in Operational Condition

Fig. 4 Force Measurement Circuit

Table- I: Technical Specifications of the Components

SN.	Components used in setup		
	Component	***Material***	***Specifications***
1.	Outer Body	5mm MS Sheet	150*100*56mm
2.	Piezoelectric Sensor		30KN
3.	Microcontroller	Arduino UNO	
4.	LCD Screens		
5.	Tool		
6	Allen key	H3, H4, H6	
7	Potentiometer		(10k ohm)
8	8 x 12 CM Universal PCB Prototype Board Double-Sided		80x 120mm
9	Metal Film Resistor		10k Ohm 0.5W
10	Proto Screw Shield 1.0 For Arduino Uno		
11	Cable for Arduino UNO (USB A to B)-		500mm
12	Power Supply with DC Plug Adapter		12V 1A
13	10 core Flat Rainbow Wire		
14	6 Pin Metal Circular Plug		

7.PARAMETERS & RESULT DATA

A. Operating Parameters

The operating parameters for the experiments were taken into consideration as following:

a) Depth of cut 1(in mm)
b) Speed 400(in rpm)

B. Calculated Parameters

Based on the operating parameters for the experiments the following measurements have been done by using the dynamometer:

a) Cutting Force 39.24 (FZ, in N)

b) Feed Force 29.43(FX, in N)
c) Thrust Force 19.62(FY, in N)
d) Resultant Force 52.82(FR, in N)

The result containing all the above-mentioned details has been mentioned in the Table-II given below at various operating parameters.

SN.	Depth of cut (mm)	Length (mm)	Diameter (mm)	Forces				Speed (rpm)	Operation
				Cutting Force Fz (N)	Feed Force Fx (N)	Thrust Force Fy (N)	Resultant Force Fr (N)		
1	1	80	40	3.09	5.90	3.64	7.58	40	Turning
2	1	79	39	8.15	8.57	7.33	13.91	40	Facing
3	1	79	39	39.24	29.43	19.62	52.82	400	Turning
4	1	79	38	19.72	19.52	9.92	29.46	630	Turning
5	1	79	37	29.50	40.23	20.2	53.82	1000	Turning

8. DISCUSSIONS

From the result we got from the experimentation, here are some of the points that are discussed regarding the costing, working and overall application of the produced dynamometer.

1) This setup is cheaper than available product in market. Kistler 9257b is available at the cost of Rs 55 lakh (approx.). This is expensive due to company has to change whole carriage mechanism as per their design. We replaced tool-post by dynamometer. Sensors directly connected with microcontroller. These changes make cheaper in price.

   When forces acting on tool, Tool transfers forces to sensors inform of pressure. Sensors convert pressure into voltage. This voltage sent to the microcontroller. In microcontroller we have predefined values with help of calibration factor. Initial calibration factor for all sensors is same, but after installation of sensors into dynamometer we got some preload which are due to pressure acting by tool holder. All forces are different due to placement of tool holder. For tare change value of calibration factor.

2) The error of dynamometer is less than 3%. We can control error by change in program. We got theoretical value is 51N and actual measured value is 52.82N. The experimental value is 51.61N, which is taken by another researcher with help of strain gauge dynamometer. The error is ±2.3%. The error due to calibration factor and preload of tool holder.

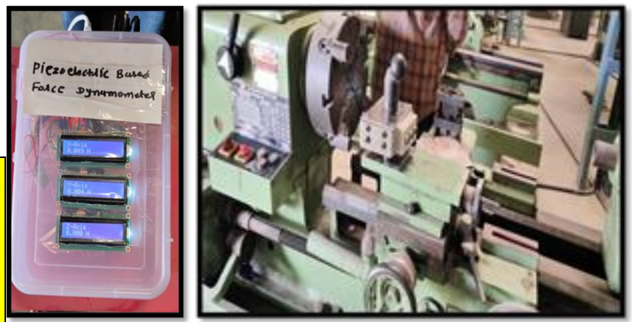

Fig. 5 Setup on Lathe

9. CONCLUSIONS

The Low-Cost Piezoelectric Tool Force Dynamometer was found to be an efficient setup for the force measurement on the Lathe. From the results of the experiment, it's been concluded that the cutting and feed forces are measured by using piezoelectric dynamometer was the finest procedure with easy application. From the result data it's been concluded that as the depth of cut increases the cutting force increases as well. The maximum result force obtained for maximum depth was 30KN, which was within the designed range. So, the design was safe within given parameters which justifies main objective of this research. The setup was built at the total cost of 22388 ₹/-, which concludes that it was a cost-effective setup. This setup could be useful in production industries as well as in engineering colleges for demonstration in order to understand the working and concept of the piezoelectric dynamometer.

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BIOGRAPHIES

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