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ANALYSIS OF THE DISTRIBUTION OF AXIAL FORCE VALUES IN DRILLING, DEPENDING ON MACHINING PARAMETERS

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ABSTRACT

Drilling is one of the most widely used material machining processes, with applications across various industries such as machinery manufacturing, automotive, and aerospace. One of the factors that influence the quality and efficiency of the machining process is maintaining a constant cutting force.

Maintaining the cutting force at a constant level during drilling is essential to ensure dimensional precision, surface quality, tool durability, operational efficiency, and safety. Implementing advanced technologies, such as automated control systems and force monitoring, can significantly contribute to process optimization and risk reduction. This ensures high-quality production with reduced costs and increased productivity.

In this study, the axial force distribution during the drilling of the aluminium alloy 2024 T351 was determined, with measurements conducted for three combinations of machining parameters. A total of 27 holes were machined using drill bits with diameters of 6, 8, and 10 mm, cutting speeds of 50, 60, and 70 m/min, and feed rates of 0.1, 0.25, and 0.4 mm/rev.

Axial force measurements were performed using a Kistler dynamometer available in the Manufacturing Engineering Department of the Faculty of Engineering at the “Dunărea de Jos” University of Galați.

KEYWORDS: cutting force, drilling, statistical control.

1. INTRODUCTION

Cutting force uniformity is an important aspect of machining processes, having a significant impact on the quality of finished parts, the life of cutting tools, and the efficiency of the manufacturing process. It refers to maintaining a constant force during cutting processes, thus ensuring uniform and controlled machining [1].

Maintaining a uniform cutting force contributes to obtaining parts with precise dimensional tolerances and superior surface quality. Force oscillations can lead to defects such as increased roughness, waviness, or even structural defects, which can compromise the integrity of the finished product. Uniform force helps prevent the occurrence of such problems, guaranteeing compliance with technical specifications.

On the other hand, a constant cutting force reduces uneven stresses on the tools, preventing premature wear and extending their service life. Tools subjected to frequent force variations can suffer localized damage or chipping, which leads to additional costs for replacement or resharpening. Therefore, uniform force contributes to reducing operating and maintenance costs.

A cutting process with uniform force also allows for the optimization of working speed and machining parameters, which leads to increased productivity. Avoiding force variations reduces the time required for unplanned adjustments or interventions, ensuring a smooth running of the production process [2].

To maintain a constant cutting force, it is necessary to take into consideration several factors, including [3, 4]:

1. Workpiece material – the structure and hardness of the material influence the cutting resistance.
2. Tool geometry – cutting angles and the sharpness of the tool’s edge contribute to a constant interaction with the material.

3. Machining parameters – feed rate, cutting depth, and cutting speed must be correctly chosen to avoid fluctuations.

4. Stability of the clamping system – a rigid clamping of both the workpiece and the tool helps reduce vibrations that can affect the uniformity of the force.

The use of monitoring equipment allows for the observation of variations that occur during machining by cutting.

This paper proposes monitoring the axial force during the drilling of alloy 2024 T351 in order to identify a potential connection between the parameters of the cutting regime and variations in the axial force.

2. MATERIALS ANS METHODS

The processed material is the 2024 T351 aluminium alloy, with its chemical composition given in Table 1, [5]. This alloy is part of the broader category of alloys generically known as duralumin.

Table 1. *Chemical composition of 2024 T351 alloy*

Component	Weight %
Si ≤	0.5
Fe ≤	0.5
Cu	3.8÷4.9
Mn	0.3÷0.9
Mg	1.2÷1.8
Cr	0.1
Zn ≤	0.25
Ti	0.15
Others elem. ≤	0.05
Al	Remainder

These alloys are known for their combination of low weight and high mechanical strength.

The alloy is widely used in various industries due to its moderate mechanical properties and corrosion resistance.

The main uses of duralumin are:

1. Aeronautical industry:

- Manufacture of fuselages and aircraft structures due to the excellent strength-to-weight ratio.
- Components for helicopters and drones.

2. Automotive industry:

- Production of lightweight chassis and structural components that help reduce vehicle weight and increase fuel efficiency.
- Rims and body parts.

3. Construction and infrastructure:

- Used in the construction of lightweight structures, bridges, railings and scaffolding due to their mechanical strength and low weight.
- Architectural elements for facades and decorative structures.

4. Naval industry:

- Manufacture of ship and fast craft structures, where low weight and water resistance are essential.

5. Sports Equipment:

- Used in the manufacture of performance bicycles, skis, and other sports equipment due to its durability and low weight.

6. Military Equipment:

- Applied in light armored vehicles and components for military aircraft due to its combination of strength and lightness.

7. Electronics Industry:

- Housing elements for laptops, mobile phones, and other gadgets due to its aesthetic appearance and mechanical properties.

8. Tool and Tool Manufacturing:

- Used in the production of lightweight and wear-resistant tools such, as hand tools and fasteners.

The mechanical characteristics of alloy 2024 T351 are shown in Table 2, [5].

Table 2. *Mechanical properties of 2024 T351 alloy*

Hardness, Brinell	120
Hardness, Rockwell A	46.8
Ultimate Tensile Strength [MPa]	469
Tensile Yield Strength [MPa]	324
Elongation at Break [%]	20
Modulus of Elasticity [GPa]	73.1
Ultimate Bearing Strength [MPa]	814
Machinability [%]	70
Shear Strength [MPa]	283

The machining was performed on a HAAS V2 machining center that allows the modification of cutting speeds and feed rates within relatively wide limits. This capability, combined with the fact that the cutting depth can be modified by choosing the appropriate diameter of the drill with which the machining is done, enables the modification of the cutting regime parameters so that the influence of these parameters on the variation of the cutting force can be studied.

Force measurement was performed with a Kisler dynamometer, the results being recorded with the dedicated DynoWare program.

The cutting regime parameters were varied within the recommended ranges for machining the afore-mentioned alloy. For each of the parameters, three values were chosen as follows:

- cutting speed. v took the values of 50, 60, 70 m/min.
- cutting edge feed. fz took the values of 0.05; 0.125 and 0.2 mm.
- cutting depth. ac took the values 3, 4 and 5mm.

With these three values for each parameter, 27 distinct cutting regimes were obtained.

For each of these regimes, the axial forces of the drills were measured at a frequency of 25000 Hz, the values being recorded in a file.

Subsequently, using the Matlab program, the portion of data corresponding to the time when the drill was in working mode was selected from the string of values. This selection was made based on the visual identification of the relevant data.

In figure 1.a., the recording of values for one of the cutting regimes (the one corresponding to the parameters ae=5 mm, fz=0.125 mm, v=50 m/min.) is presented.

In figure 1.b. the area selected for further analysis is presented.

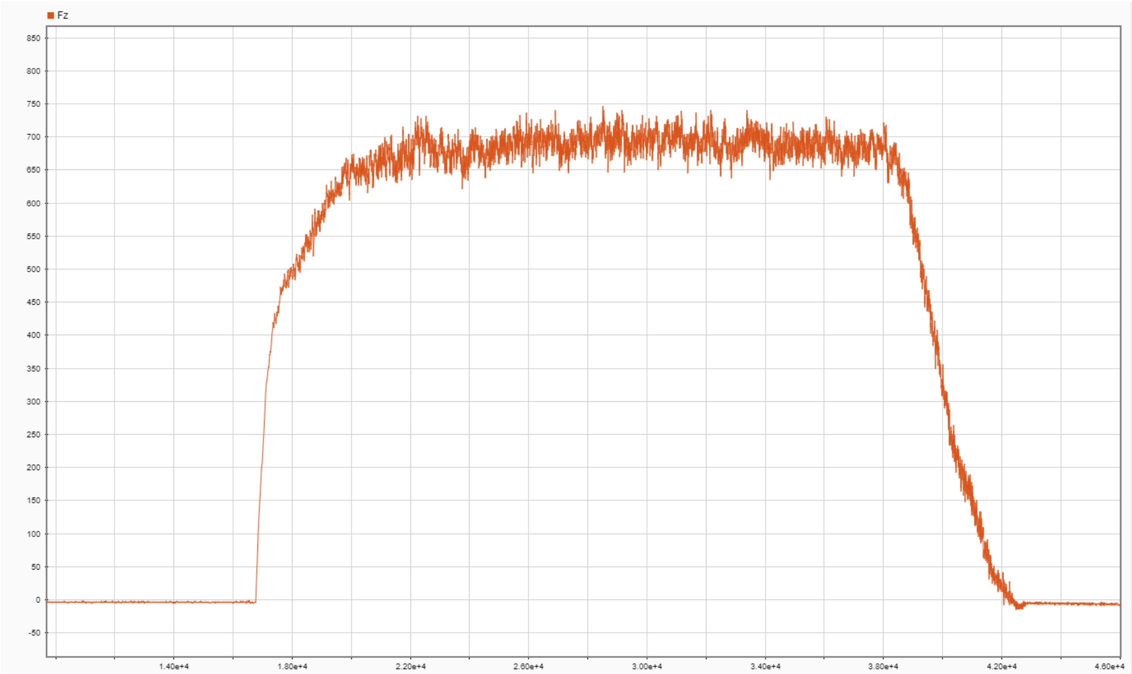

Fig. 1.a. *Axial force registration*

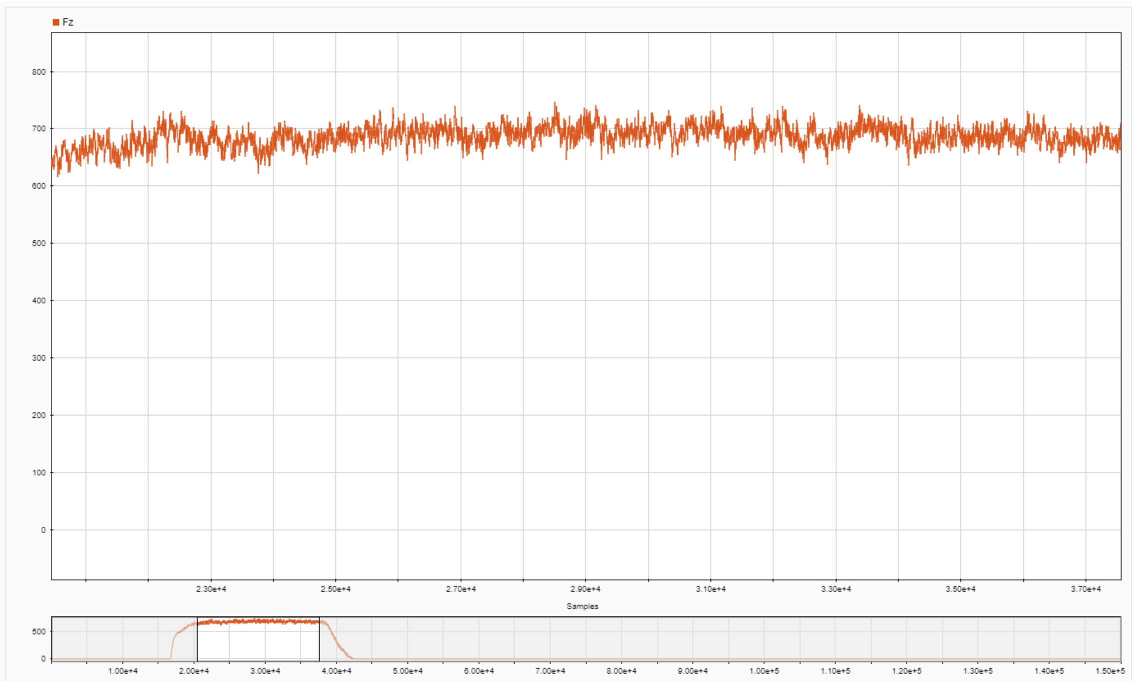

Fig. 1.b. *Selection zone*

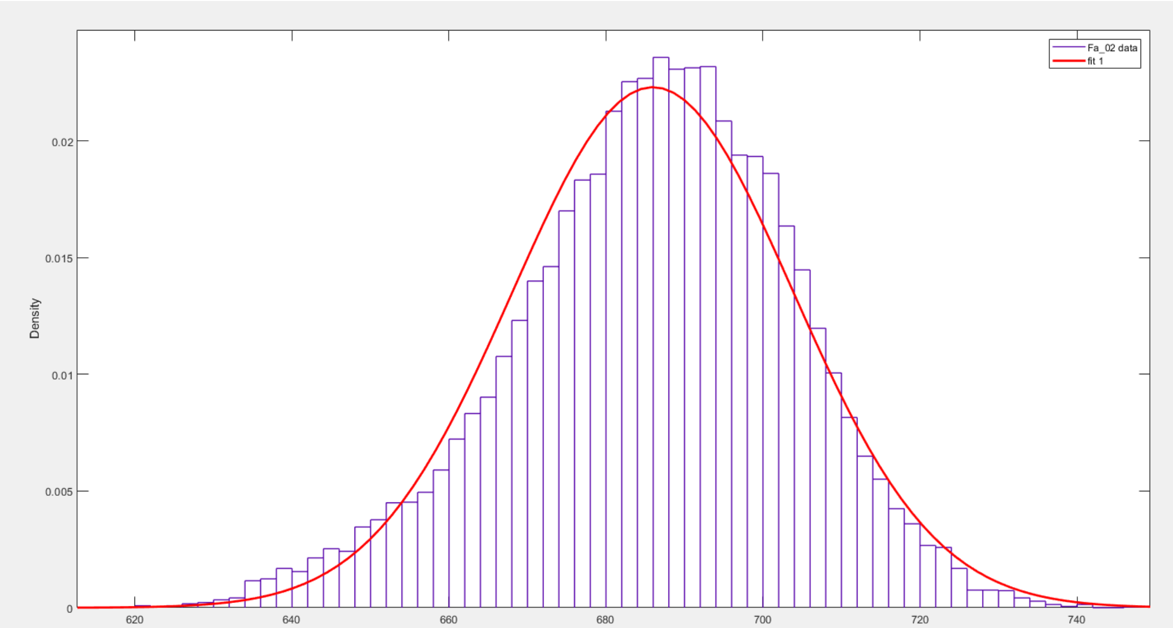

Fig. 2. *Distribution of axial force values for drills (v=50 m/min.; fz=0,125 mm; ae=5 mm)*

Table 3. *Statistical parameters of distributions*

Crt. no.	ae [mm]	v [m/min]	fz [mm]	Mean [N]	δ
1	5	50	0.050	349.351	9.042
2	5	50	0.125	685.971	17.892
3	5	50	0.200	1057.759	30.121
4	5	60	0.050	348.876	11.712
5	5	60	0.125	715.459	19.413
6	5	60	0.200	1072.444	26.197
7	5	70	0.050	351.824	9.5781
8	5	70	0.125	734.170	19.215
9	5	70	0.200	1076.887	37.855
10	4	50	0.050	404.282	10.674
11	4	50	0.125	817.043	23.111
12	4	50	0.200	1229.820	32.958
13	4	60	0.050	419.759	15.389
14	4	60	0.125	848.347	26.200
15	4	60	0.200	1233.932	37.041
16	4	70	0.050	423.420	12.159
17	4	70	0.125	850.205	22.900
18	4	70	0.200	1223.776	37.114
19	3	50	0.050	179.921	9.260
20	3	50	0.125	433.613	18.045
21	3	50	0.200	688.720	28.196
22	3	60	0.050	187.193	9.424
23	3	60	0.125	433.429	15.688
24	3	60	0.200	700.916	26.896
25	3	70	0.050	191.675	10.604
26	3	70	0.125	460.869	16.898
27	3	70	0.200	697.561	23.749

For each of the cutting regimes, a similar procedure was carried out.

With the same Matlab program, the distribution of values for the selected areas was identified. Table 3 presents the main statistical parameters of the distribution, while Figure 2 shows the graphical representation of the distribution for the specified cutting regime.

To identify the potential influence of each cutting regime parameter on the axial force distribution, a multi-criteria analysis of variance (ANOVA) was applied, [6]. The analysis was conducted in the Matlab program.

3. EXPERIMENTAL DATA PROCESING

From the analysis of the experimental data presented in Table 3, the effect of each of the three cutting regime parameters on the distribution of the drill axial force values can be determined.

The analysis was performed using the multicriteria method in the Matlab program, [7].

The results are presented in Table 4.

Table 4. *The results of the ANOVA analysis*

Source	Sum Sq.	d.f.	Mean sq.	δ	p
ae	195.75	2	97.876	14.25	0.0023
v	7.24	2	3.621	0.53	0.6094
fz	1852.85	2	926.423	134.88	0
Error	54.95	8	6.868		
Total	2205.05	26			

The values obtained for the probability of influencing the distribution of axial force values indicate that both the depth of cut and the feed have a significant impact on this aspect, while the cutting speed does not affect the respective distribution.

This can also be observed if the distributions for each of the three parameters considered are graphically represented. Figures 3-5 show these distributions.

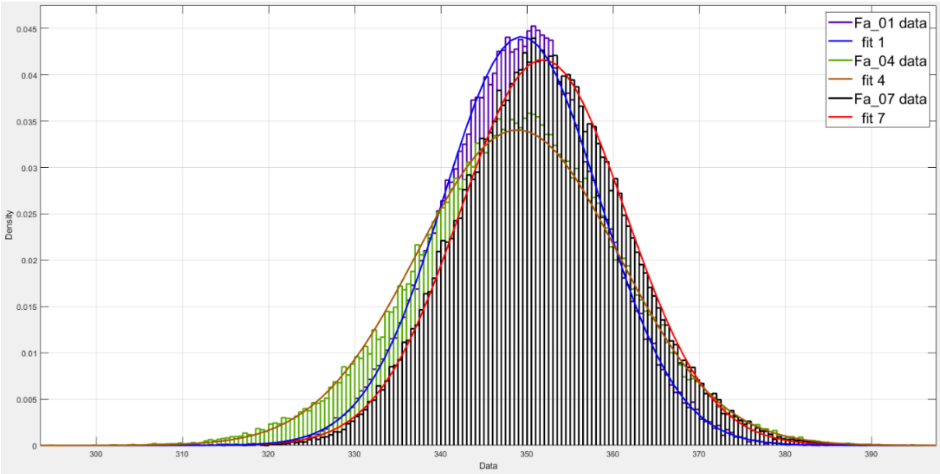

Fig. 3. *Axial forces values distribution for ae=5 mm; fz=0.05 mm (Fa_01: v=50 m/min.; Fa_04: v=60 m/min.; Fa_07: v=70 m/min.)*

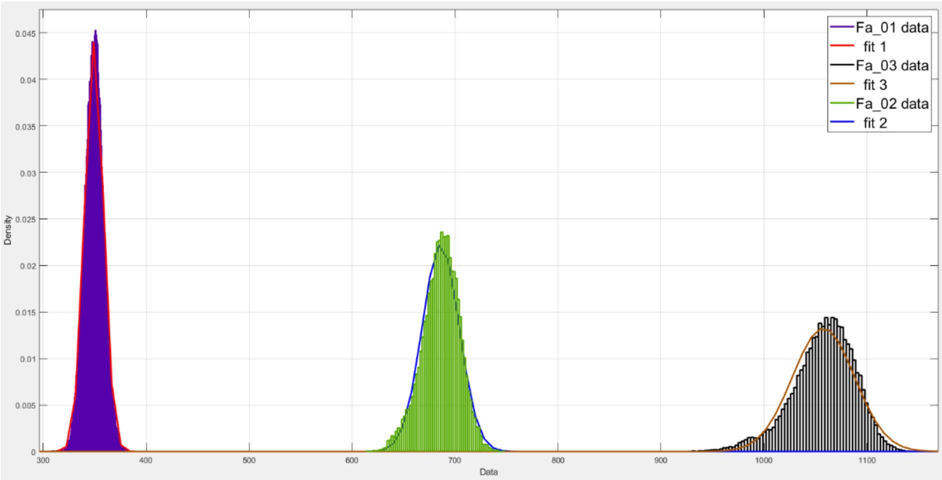

Fig. 4. *Axial forces values distribution for ae=5 mm; v=50 m/min. (Fa_01: fz=0.05 mm.; Fa_02: fz =0.125 mm.; Fa_03: fz =0.2 mm.)*

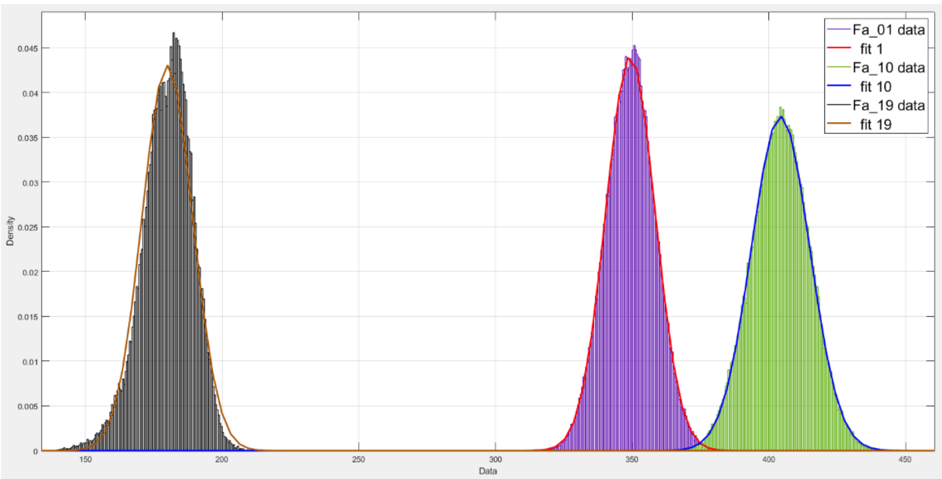

Fig. 5. *Axial forces values distribution for v=50 m/min.; fz=0.05 m/min. (Fa_01: ae=5 mm.; Fa_10: ae =4 mm.; Fa_19: ae =3 mm.)*

4. CONCLUSIONS

Maintaining a uniform cutting force value has a direct impact on machining accuracy and the quality of the machined surface.

In this paper, a study was conducted on the potential influence of cutting regime parameters on the uniformity of axial force when drilling 2024 T351 aluminium alloy.

The analysis of experimental data demonstrated that both the cutting depth and the feed rate significantly influence the distribution of axial force values.

It could be observed that a lower feed rate favours a smaller dispersion of these force values, thus resulting in a greater uniformity of the axial force.

However, it must be considered that a lower feed rate will lead to a lower productivity in the process.

In conclusion, the choice of feed rate must also take into account the importance we give to this productivity in each case.

If it is considered that maintaining a constant axial force takes precedence, then lower feed rates should be chosen, possibly compensating with higher cutting speeds.

If cutting productivity is important, for example when finishing machining is to be performed after drilling (e.g., reaming), higher feed rates can be chosen, accepting a more uneven distribution of axial force.

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