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# INVESTIGATIONS OF THE QUALITY CHARACTERISTICS OF HOLES MADE BY USING INDEXABLE DRILLS

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***Abstract:*** *The paper presents an experimental investigation on a high productivity drilling process. A new type of a high-performance drill with replaceable head (Dormer Hydra) was used to process accurate holes in steel DIN ST52-3. The Dormer Hydra drill is designed with replaceable head in order to reduce the manufacturing cost. The drill body is made out of steel and the head is from carbide. The experimental data was studied by using the Response Surface Methodology. The correlation between main process parameters and holes quality characteristics was studied.*
***Key words:*** *drilling, CNC machining, process parameters, optimization*

## 1. INTRODUCTION

A drilling operation consists of machining a hole in solid material [1], [2]. It is widely applied in common manufacturing industries but also in top industries like automotive or aerospace [1], [3]–[5]. In an aircraft up to millions of accurate holes can be drilled [6]. Drilling can be the first step for a variety of machining operations, like boring, tapping or reaming [1]. Drilling is a challenge when it comes to high quality and productivity requirements [4]–[6].

The dimensional requirements of the holes are diameter and depth. Geometrical tolerances like dimensional tolerance, positional deviation and concentricity are the main quality characteristic of the drilled hole [7] [1], [4]. Surface roughness and topography are a key quality parameter on the process. The requirement is to decrease the surface roughness [1], [2]. The surface texture has a vital role in manufactured part functionality [1]. A high surface roughness and cracks on the hole surface increases the risk of crack propagation [6], [8].Burr formations at the top and bottom of the hole are common process problems [4], [9]. It can promote, under the stress of flight, structural weaknesses [6], [8].

Continuous long chips formation could introduce on drilled material thermal and mechanical stresses [10]. Tool wear is an important aspect of the process. Drilling operation can be conducted dry or with cutting fluids. Dry cutting is an environmentally friendly method, but tool wear is higher and productivity is lower than when cutting fluid is used [5]–[8].

The main types of drills are twist drills made from high-speed steel [2] or solid carbide [6], [7] and indexable drills with steel body and replaceable cutting areas made out of solid carbide [11]. The indexable drills were designed to increase the machining efficiency, and also to maintain the quality characteristics of the drilling process at a high level [11], [12]. The indexable drills can use changeable inserts or a replaceable head. To machine holes at: high accuracy, low surface roughness, high productivity, low tool wear and good chips evacuation the process parameters must be optimized [3], [5], [6]. The paper presents a study of the drilling process parameters influence on the quality characteristics. The surface quality, dimensional and cylindrical deviation of the machined holes were investigated. Response Surface Methodology (RSM) was involved in the study.

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## 2. CUTTING TOOL PRESENTATION

In this study a high-performance drill with a replaceable head manufactured by Dormer/Pramet was selected. In figure 1 is presented the drill and the range of materials which can be machined.

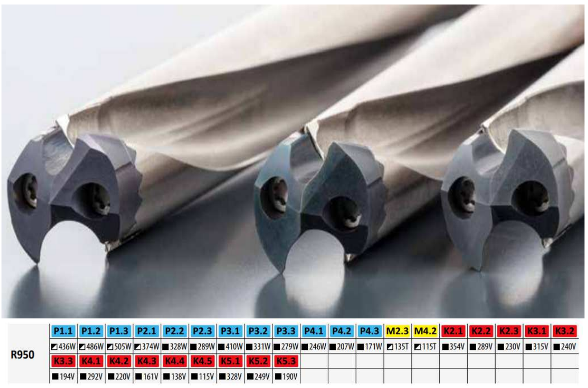

**Fig. 1.** The drill used in this study: Dormer Hydra [12].

The Dormer Hydra drill is designed with replaceable head in order to reduce the manufacturing cost [12]. The drill body is made out of alloyed steel and the cutting area is made from carbide. The experiments were made with a 12.5 mm internal cooling drill with H853 body and R950 insert. Figure 2 shows the 3xD hydra body with 12.5 mm diameter and 3xD length (44 mm).

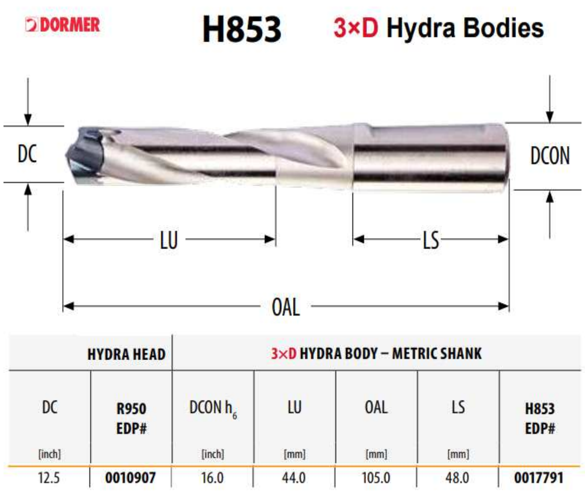


**Fig. 2.** The drill body dimensions [12].

In case of the drill, a 12.5 mm R950 carbide insert was selected, designed for machining steel P 1.1- 4.4 (see figure 3).

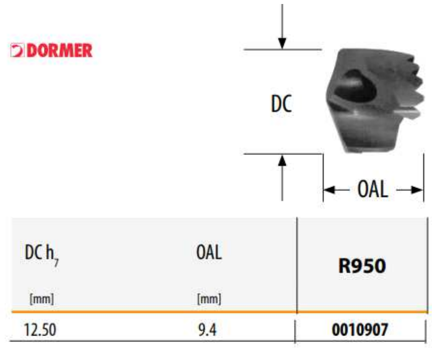


**Fig. 3.** The drill insert dimensions [12].

## 3. EXPERIMENTAL PROCEDURES

The Central Composite Design (CCD) method was chosed to obtain the optimal combination of process parameters. This design of experiments (DOE) method helps to study the connection between input variables and output variables. Because of the low number of input variables, cutting speed ($V_c$) and feed rate ($f_n$), CCD is the proper method for DOE, when the drilling process is analyzed [7].

Based on CCD a number of 13 trials resulted and the combination of the process parameters are shown in table 1. The $V_c$ was varied from 70 to 110 m/min, and in the case of the $f_n$ the variation was from 0.05 to 0.4 mm/rev.

*Table 1*

**The process parameters used in experiments.**

| No. | $V_c$ [m/min] | $f_n$ [mm/rev] |
|---|---|---|
| 1. | 90 | 0.05 |
| 2. | 90 | 0.23 |
| 3. | 70 | 0.23 |
| 4. | 90 | 0.23 |
| 5. | 75.86 | 0.35 |
| 6. | 90 | 0.4 |
| 7. | 90 | 0.23 |
| 8. | 90 | 0.23 |
| 9. | 104.14 | 0.1 |
| 10. | 90 | 0.23 |
| 11. | 104.14 | 0.35 |
| 12. | 75.86 | 0.1 |
| 13. | 110 | 0.23 |

The steel DIN ST52-3 is the material selected for experimental study. The workpiece was a laminated bar with 50x50x300 mm dimensions (see figure 6).

**Fig. 4.** The drill and tool holder.

13 holes with 12.5 x 25 mm dimension were machined on a 3 axes CNC milling machine HAAS VF2 SS. Each experimental trial was repeated three times. During the tests, internal cooling with 50 BAR and G81 canned cycles were used. In figure 3 is presented the drill and the Weldon tool holder (see figure 4) and figure 5 shows the experimental setup.

**Fig. 5.** The experiment setup.

**Fig. 6.** The 13 experimental trials.

The holes dimensional accuracy was measured with 3D measurement equipment Aberlink and for surface roughness (Ra) was used Mitutoyo Surftest SJ-210. Table 2 shown the analyzed process quality characteristics (dimensional and cylindricity deviation of the holes and surface roughness Ra).

*Table 2*

**The experimental results.**

| No. | Vc [m/min] | fn [mm/rev] | Dimensional deviation [mm] | Cylindricity deviation [mm] | Ra [μm] |
|---|---|---|---|---|---|
| 1. | 90 | 0.05 | 0.007 | 0.017 | 2.98 |
| 2. | 90 | 0.23 | 0.018 | 0.025 | 2.15 |
| 3. | 70 | 0.23 | 0.037 | 0.039 | 1.9 |
| 4. | 90 | 0.23 | 0.03 | 0.031 | 2.28 |
| 5. | 75.86 | 0.35 | 0.046 | 0.037 | 4 |
| 6. | 90 | 0.4 | 0.043 | 0.027 | 3.78 |
| 7. | 90 | 0.23 | 0.007 | 0.021 | 1.36 |
| 8. | 90 | 0.23 | 0.004 | 0.017 | 1.707 |
| 9. | 104.1 | 0.1 | -0.011 | 0.013 | 0.99 |
| 10. | 90 | 0.23 | 0.024 | 0.026 | 1.58 |
| 11. | 104.1 | 0.35 | 0.052 | 0.028 | 3.66 |
| 12. | 75.86 | 0.1 | -0.004 | 0.016 | 1.46 |
| 13. | 110 | 0.23 | 0.01 | 0.031 | 2.723 |

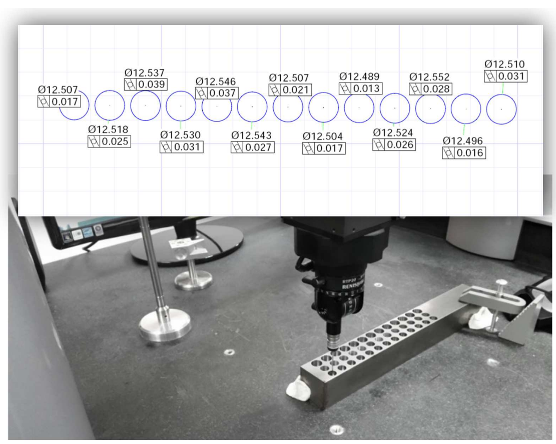

**Fig. 7.** Dimensional and cylindricity deviation of the holes measurement

The results obtained during the experiments (see table 2 and figure 7) was analyzed by using Design Expert software.

## 4. RESULTS AND DISCUSSIONS

To study the experimental results a Response Surface Methodology (RSM) was involved. RSM consists of developing regression mathematical models [6], [7], [13]. This statistical method develops a correlation between independent and dependent variables of the process [13]. The effect of the input variables ($V_c$ and $f_n$) on output variables (hole accuracy and surface roughness) was studied.

### 4.1 The analysis of the hole accuracy

The holes dimensional accuracy is a key quality aspect on the high-performance drilling process. Dimensional deviation and cylindricity are analyzed parameters on this study.

To analyze the dimensional deviation of the process an empirical mathematical model was obtained by analyzing the experimental data. In this case a linear mathematical model was significant. The dimensional deviation model looks as:

$$\text{Dimensional deviation (mm)} = 0.0141 - 3.46339 \times E-004 \times V_c + 0.1655 \times f_n \quad (1)$$

The value of the "Pred R-Squared" is 0.84 which proves an accurate prediction for this new model.

By analyzing the graphical representation from figure 8, dimensional deviation varies between -0.011 and 0.052 mm. To decrease the dimensional deviation is indicated to decreases the feed rate and to increases the cutting speed.

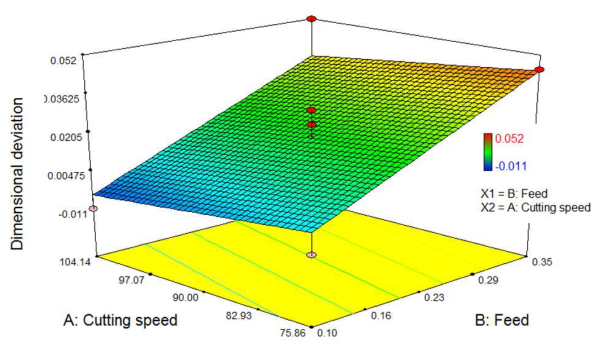


**Fig. 8.** Effect of $V_c$ and $f_n$ on dimensional deviation (-0.011- 0.052 mm).

The hole cylindricity was also analyzed. The empirical mathematical model was a linear mathematical model. The regression model is presenting as:

$$\text{Cylindricity deviation (mm)} = 0.0323 - 2.0606 \times E-004 \times V_c + 0.05 \times f_n \quad (2)$$

The value of the "Pred R-Squared" in this case is 0.91.

Figure 9 presents the dependence between input variables $V_c$ and $f_n$ and output variable hole cylindricity deviation (mm). The variation range of the cylindricity is between 0.013 and 0.039 mm. Like is shown in figure 3.3 to decrease the hole cylindricity it is indicated to decrease $V_c$ (up to 104 m/min) and to decrease $f_n$ (up to 0.1 mm/rev). Both input parameters have a strong influence on the hole cylindricity.

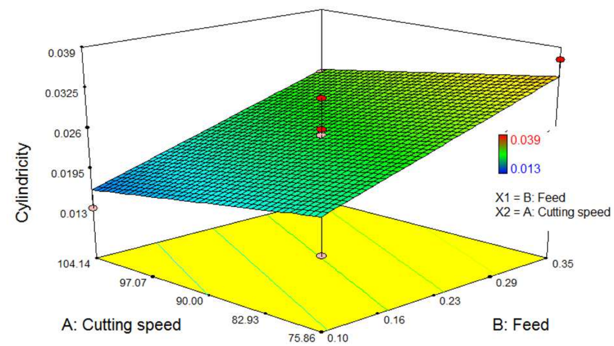


**Fig. 9.** Effect of $V_c$ and $f_n$ on cylindricity deviation (0.013 - 0.039 mm).

### 4.2 The surface roughness analyses

Surface hole quality is another important quality aspect when a drilling process is study. The significant regression model for the hole surface roughness is quadratic model:

$$\text{Surface Roughness Ra} = 9.6157 - 0.15269 \times E-004 \times V_c - 15.917 \times f_n + 0.0185 \times V_c \times f_n + 8.424E-004 \times V_c^2 + 45.893 \times f_n^2 \quad (3)$$

A value by -0.7345 of "Pred R-Squared" implies a good prediction of the developed model. During the experimental trails was obtain a variation of the surface roughness between 0.99 up to 4 µm.

Figure 10 shows the correlation between input variables (Vc and fn) and output variable hole surface roughness (Ra/µm). The surface roughness Ra increases from 0.9 up to 3.3 µm when fn increases from 0.05 up to 0.4 mm / rev. In case of cutting speed $V_c$, using a variation from 75 up to 104 m/min was observed a very low influence. The same aspects was observed by Muhammad Aamir during drilling of Al2024 alloy with carbide drills [6].

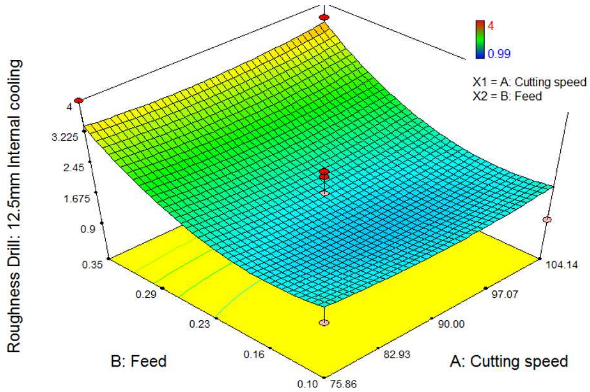


**Fig. 10.** Effect of $V_c$ and $f_n$ on surface roughness (Ra = 0.99 – 4 µm)

## 5. CONCLUSION

The paper presents an experimental investigation on machining accurate holes in steel DIN ST52-3 using a high-performance drill with replaceable head.

Based on this experimental study, it can be concluded:

- Accurate holes could be machined (up to 0 mm dimensional deviation and 0.013 mm in case of cylindricity deviation) using proper process parameters and conditions.

- It is indicated to decrease the feed rate and to increase the cutting speed to improve the hole dimensional accuracy (to decrease the dimensional and cylindricity deviations).

- For decreasing the surface roughness (up to 0.99 µm) it is indicated to decrease the feed rate (0.05 mm/rev). The cutting speed does not have a relevant influence on the surface roughness.

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**Investigaţii asupra caracteristicilor de calitate ale găurilor realizate cu burghie cu plăcuțe indexabile**

Lucrarea prezintă un studiu experimental asupra unui procesului de găurire cu productivitate ridicată. Un nou tip de burghiu de înaltă performanță cu zona activă interschimbabilă (Dormer Hydra) a fost utilizat pentru a prelucra găuri precise în oțel DIN ST52-3. Burghiul Dormer Hydra este proiectat cu cap interschimbabil pentru a reduce costul de producție. Corpul burghiului este realizat din oțel, iar zona activă este din carbură. Datele experimentale au fost studiate prin utilizarea metodologiei de suprafeței de răspuns (RSM). Au fost analizate efectele parametrilor principali de proces (viteza de aschiere și avansul) asupra preciziei de prelucrare și rugozitatea suprafeței.

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