# EXPERIMENTAL STUDY OF THE CUTTING FORCES IN TURNING MILD STEEL C45

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**Abstract:** *Cutting forces are one of the most important technological parameters in turning, being used for dimensioning of the cutting tools, as well as for the evaluation of the necessary machining power. Cutting forces are also having a major influence on the machining system stability and on the dimensional accuracy of the machined work piece.*

**Keywords:** *Cutting forces, feed rate, depth of cut*

## 1. Introduction

The experimental study of the cutting conditions involves techniques for the measurement of the cutting forces.

In classical turning process of steel, in the contact area between tool and material appears a cutting force, which can be decomposed after three orthogonal components. In practice, the resulting value of the cutting force is less of importance, relevant being its components, which are used in several calculations, as for example: fixing devices for the material, tools, resistance of the various parts of the machine tools, to calculate the propulsion power of the driving electric motors, the calculation of processing accuracy a.s.o.

Figure 1 [4] shows the decomposition scheme of the resulting force in its three orthogonal components: feed force Ff , radial force Fr and tangential force Ft.

The feed force Ff is oriented in the feed direction, which is the same direction as the longitudinal axis of the piece. This component is used for dimensioning the tool, the feed mechanism, a.s.o.

The radial force Fr is oriented in radial direction seeking to dismiss the toll, and to depart it from the machined surface. This component affects the dimensional accuracy, as well as the geometric shape accuracy of the machined work piece.

The tangential force Ft is oriented in turning direction, being the most im-portant component in size and role. This component determines the size of the resistant torque that has to be transmitted by the main shaft of the machine tool and the power consumption during the cutting process.

The resultant cutting force can be calculated with following equation:

$$F = \sqrt{F_f^2 + F_r^2 + F_t^2} \qquad (1)$$

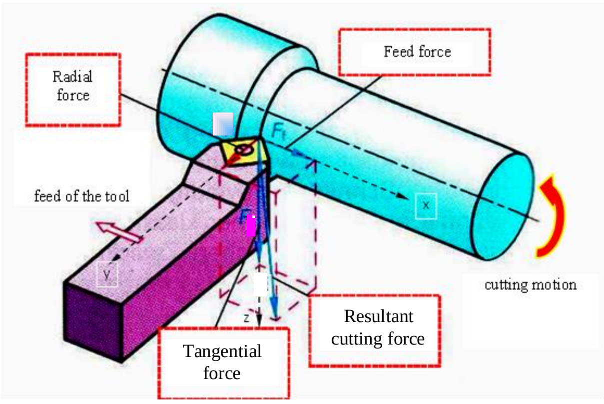


**Figure 1:** *Orthogonal components of cutting force in turning [4]*

The specific literature in domain of cutting is indicating various expressions for calculating the components of the cutting force, which were obtained by analytical means or through experimental methods. For practical calculations, there are pre-ferred the experimental obtained relationships because they yield closer values to reality than the analytical formulas, as a result of the fact that the analytical relations have been obtained after many simplifying assumptions.

The most common equation available for the estimation of the cutting forces is according to [4]:

$$F_i = C_{F_i} \cdot s \cdot t \qquad (2)$$

where:

$C_{Fi}$- specific cutting energy coefficient [N/ $mm^2$];

s- feed rate [mm/ rev];

t- depth of cut [mm];

i- index for the three components of the cutting forces (f, r and t).

## 2. Set-up of the experimental study

This research was primarily focuses on turning of mild steel of grade C45, using HSS made tools, due to their lower cost, ready availability and a wide range of applications. The influence of cutting parameters on cutting forces can be studied by using the adjusted statistical approach.

The experiments were carried out on a mild steel round bar having an initial diameter of 70mm and a length of 500 mm. Turning was performed on an usual lathe (type SN 560), by using standard high speed steel tools, without the use of cutting fluid. Machining has been continued until the flank wear of the tool achieved a maximum value $VB_{max}$= 0,6 mm. Details of the experiment are listed in table 1.

**Table 1**

| **Details of the experiment** | |
|---|---|
| **Machine tool** | **Turning lathe SN 560** |
| **Tool specification** | |
| Material grade | HS6-5-2C (1.3343), acc. to SR EN ISO 4957 |
| **Work piece material** | |
| Steel grade | C45 (1.0503), acc. to SR EN 10.083-2 |
| Hardness | Brinell 200 |
| **Cutting conditions** | |
| Turning speed n [rev/ min] | 200; 315; 400; 500; 630 and 800 |
| Cutting speed v [m/min] | 43,96; 69,24; 87,92; 109,9; 138,47 and 175,84 |
| Feed rate s [mm/ rev] | 0,1; 0,2; 0,315; 0,4; 0,63 and 0,8 |
| Depth of cut t [mm] | 0,5; 0,75; 1 and 1,5 |
| Cutting fluid | none |

For measuring the cutting forces was used a dynamometer type 9257B from KISTLER.

Schematic diagram of the experimental set-up is shown in figure 2.

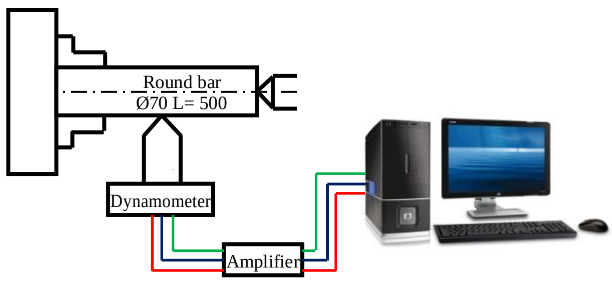


**Figure 2:** *Set-up of the experimental study*

## 3 Experimental results and discussion

The cutting parameters and the measured cutting forces are shown in table 2.

**Table 2**

| No. | Turning speed n [rev/min] | Cutting speed v [m/min] | Feed rate s [mm/rev] | Depth t [mm] | Feed force $F_f$ [N] | Radial force $F_r$ [N] | Tang. force $F_t$ [N] |
|---|---|---|---|---|---|---|---|
| 1 | 200 | 43,96 | 0,2 | 0,5 | 355 | 195 | 460 |
| 2 | 315 | 69,24 | | | 285 | 165 | 390 |
| 3 | 400 | 87,92 | | | 280 | 161 | 385 |
| 4 | 500 | 109,9 | | | 266 | 152 | 370 |
| 5 | 630 | 138,47 | | | 246 | 138 | 353 |
| 6 | 800 | 175,84 | | | 228 | 124 | 338 |
| 7 | 315 | 69,24 | 0,2 | 0,5 | 266 | 236 | 475 |
| 8 | | | | 0,75 | 419 | 294 | 682 |
| 9 | | | | 1 | 520 | 314 | 796 |
| 10 | | | | 1,5 | 708 | 327 | 1052 |
| 11 | 315 | 69,24 | 0,1 | 1 | 141 | 58 | 200 |
| 12 | | | 0,2 | | 277 | 135 | 374 |
| 13 | | | 0,315 | | 383 | 139 | 484 |
| 14 | | | 0,4 | | 496 | 167 | 583 |
| 15 | | | 0,63 | | 645 | 177 | 724 |
| 16 | | | 0,8 | | 756 | 185 | 747 |

### 3.1 Effect of cutting speed on cutting forces

The results presented in figure 3 are showing the effect of the cutting speed on the evolution of the cutting forces. It can be concluded that an increase of the cutting speed leads to a reduction of the cutting forces.

This phenomenon can be explained by the fact that by increasing the cutting speed, the temperature in the cutting zone is raising, which makes the metal cutting more plastic and, consequentially, the efforts necessary for machining are decreasing. By examining the shape of the three curves, it has been recorded a very clear decrease of all the three components of the cutting force until a cutting speed of 69 m/min, beyond this limit the decrease being slower.

It is noted that the three components of the cutting force ($F_f$, $F_r$ and $F_t$) are decreasing each with 35,77%, 36,41%, respective 26,52%, by increasing the cutting speed from 43,96 to 175,84 m/ min.

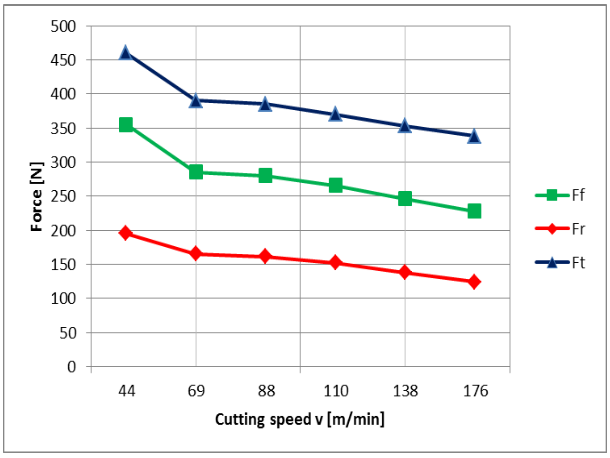


**Figure 3:** *Cutting forces vs. cutting speed at t= 0,5 mm and s= 0,2 mm/rev*

According to the above results, the radial force ($F_r$) is the most sensitive component for the variation of the cutting speed, being followed by the feed force ($F_f$) and lastly by the tangential cutting force ($F_t$).

Based on experimental data, obtained by maintaining a constant feed rate of s= 0,2 mm/ rev., respective a constant depth of cut t= 0,5 mm, it have been deducted following mathematical formulas which are showing the variation of the cutting force components for a cutting speed average v= 43,96 - 175,84 m/min.

$$F_f = 350{,}16 \cdot v^{-0{,}224} \quad (3)$$

$$F_r = 197{,}75 \cdot v^{-0{,}226} \quad (4)$$

$$F_t = 452{,}84 \cdot v^{-0{,}158} \quad (5)$$

### 3.2 Effect of depth of cut on cutting forces

The obtained values (Figure 4) are illustrating the evolution of the cutting forces depending on the depth of cut. By increasing the depth of cut from 0,5 to 1,5 mm, it has been recorded an increase of the cutting forces ($F_f$, $F_r$ and $F_t$) of 166,17%, 38,55%, respective 121,47%.

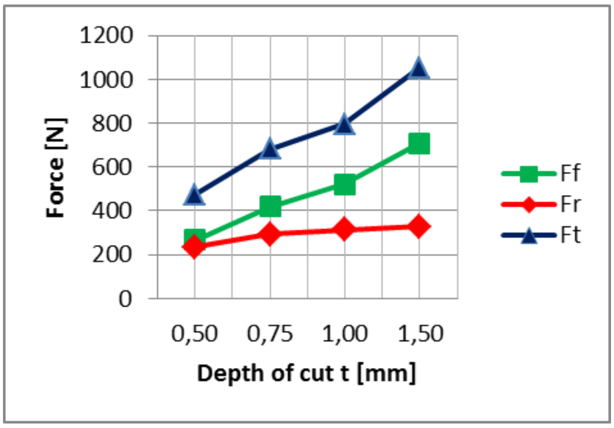


**Figure 4:** *Cutting forces vs. depth of cut at v= 69,24 m/ min and s= 0,2 mm/rev*

It is noted that the feed force ($F_f$) is very affected by the variation of the depth of cut, being followed by the tangential force ($F_t$) and lastly by the radial force ($F_r$).

Based on experimental data, obtained for a feed rate of s= 0,2 mm/ rev., respective for a cutting speed of v= 69,24 m/ min, it have been deducted following mathematical formulas which are showing the variation of the cutting force components for the depth of cut average t= 0,5 – 1,5 mm:

$$F_f = 262{,}24 \cdot t^{0{,}6799} \quad (6)$$

$$F_r = 240{,}56 \cdot t^{0{,}2376} \quad (7)$$

$$F_t = 468{,}06 \cdot t^{0{,}545} \quad (8)$$

### 3.3 Effect of feed rate on cutting forces

The results presented in figure 5 are showing the effect of the feed rate on the evolution of the cutting forces. By increasing the feed rate, the section of sheared chips is increasing and consequentially the removal of material requires higher forces. It can be observed that for all the tested feed rates the main force is dominating, compared to both others forces.

The effects of the feed rates on the cutting forces are as follows: the increase in the feed rate from 0,1 to 0,8 mm/ rev increases the components of the cutting forces ($F_f$, $F_r$ and $F_t$) successively of: 436,17%, 218,97 and 273,5%.

It is noted that the feed force ($F_f$) is very affected by the feed rat, being followed by the tangential force ($F_t$) and lastly by the radial force ($F_r$).

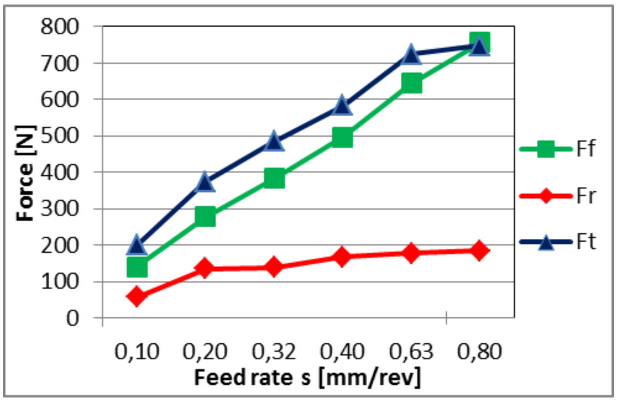


**Figure 5:** *Cutting forces vs. feed rate at v= 69,24 m/ min and t= 1 mm*

Similar to the two previous presented cases, by maintaining a constant cutting depth of t = 1 mm, respective for a cutting speed of v= 69,24 m/ min, it have been deducted following mathematical formulas which are showing the variation of the cutting force components for the feed rate average s= 0,1 – 0,8 mm/ rev:

$$F_f = 141{,}34 \cdot s^{0{,}9298} \quad (9)$$

$$F_r = 68{,}727 \cdot s^{0{,}6131} \quad (10)$$

$$F_t = 209{,}67 \cdot s^{0{,}7448} \quad (11)$$

## 5. Conclusions

The tests of longitudinal turning, carried out on C45 steel grade, using HSS made tools, without the use of cutting fluid, enabled us to study the influence of the cutting parameters on the cutting forces.

It could be concluded that, by raising the cutting speed (v), the cutting forces are decreasing, while, by raising the depth of cut (t) and the feed rate (s), the components of the cutting force ($F_f$, $F_r$ and $F_t$) are increasing,

It is also to be noted that from the three cutting parameters (v, t and s) the increase of the feed rate has greatly affected the cutting forces. Furthermore, the most sensitive component of the cutting force at the variation of the cutting parameters is the feed force ($F_f$).

The established mathematical models have defined the degree of influence of each component of the cutting parameters on the cutting forces.

While the results declared through this experimental work may be generalized to a considerable extend, until working on Mild Steel and using HSS tool, the mathematical models are limited to the extreme range of the specified cutting parameters values.

## 5. References

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