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RESEARCH

Neural Network Modeling of Cutting Fluid Impact on Energy Consumption during Turning

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ABSTRACT

This paper presents a part of research on power consumption differences between various cutting fluids used during turning operations. An attempt was made to study the possibility of artificial neural network to model the behavior function and predicting the electrical power consumption. Friction factor of examined cutting fluids was also measured to describe a more complete picture of investigated cutting fluids characteristics. It was discovered that wide spectrum of characteristics is present in today's market and that artificial neural networks are suitable for purpose of modeling the power consumption of the lathe during machining. This paper could be used as a foundation for later database building where it would be possible to predict how certain cutting fluid will behave in a specific machining parameter combination.

1. INTRODUCTION

It is well known that cutting fluids are, in a major scale, influencing the complete process of cutting. This influence is mostly visible through change of cutting tool life. Use of cutting fluid is increasing tool life and thus cutting down expenses in this area. It is also common knowledge that cutting forces are decreasing which also mean that power consumption of machine will be lower. One must take into consideration proper use of mentioned cutting fluids because not all are universal and adequate type should be chosen in order to increase economy of production [1].

In some point in time it was obvious that new trend has to be set and more accents put on development and testing of new types of cutting fluids, gases or vapours and also improvement of feed principle to a cutting zone. This trend prevails and vast progress has been done to this day. But with such large amount of cutting fluids it is sometimes difficult to choose the optimal one. There are numerous manufacturers and even more types of cutting fluids each for specific application. According to stated above, it seems that by solving one problem a wide spectrum of others has been created. But this is more just a setback than a real problem and it can be easily solved by employing investigation of influence for cutting fluids and their effect on cutting process.

With this fact in mind, here presented, research has been realized. Partial amount of results will be shown as an indicator of wide spectrum of cutting fluids attributes regarding power consumption of a lathe. As a result of this research there would be dependencies for proper selection of the cutting fluids and elimination of wrong selection [2].

Thorough out the history attempts were made to discover dependencies between cutting fluids and some of the output parameters of the machining processes [3-5]. The cutting fluid manufacturers are also performing tests regarding characteristics of their products but those are all internal tests and not all of them are performed following the same procedure. In order to compensate this shortage of uniformity in evaluation of cutting fluids, a uniform method will be applied to all examined fluids. Consumption of electrical energy will be monitored and Artificial Neural Network (ANN) will be used to model available data and later used to predict the behaviour of a cutting fluid under specific, unknown, circumstances.

2. EXPERIMENT

2.1 Tool

For the purpose of experiments following equipment has been used: conventional lathe SN 50 with tool holder of maker Mitsubishi type MWLNR 2020K08 for exchangeable tool inserts wit WNMG shape. Sandvik Coromant was chosen as a cutting inserts supplier because of its presence in geographical area for which research has been conducted. Cutting inserts type WNMG-432-PR 4225 were used for machining purposes of widely used material, steel C45 (EN 10083-2-91). Shape of material for longitudinal turning was a rod Ø90 mm which was prefabricated to Ø85 mm. Entire section of workpiece was splitted by 3 mm deep grooves into 15 mm wide sections, each for one combination of cutting parameters. For transversal turning the shape of material was a pipe with outer diameter Ø125 mm and wall thickness of 14 mm. Outer diameter of the pipe was prefabricated to Ø124 mm and inner to Ø100 mm.

2.2 Cutting environment

Number of examined cutting fluids was thirteen. Every sample of tested cutting fluid was mixed with water according to instructions provided by the manufacturer. Principle which was used during preparation of cutting fluids was oil to water. This has been a general rule and it is recommended by all manufacturers. Cutting fluids were coded as CF.1 – CF.13 in order to conceal manufacturers name and data which could subsequently harm their reputation and cause financial loss. This is simply a conduct of unwritten ethics and will in no way influence relevance of scientific data gathered during research. One of the goals of this paper was to investigate possible range of differences among various cutting fluids and not to propagate certain manufacturer or degrade others. Next a preparation of correct mixture of oil and water was done using the volumetric flask. Mixture concentration was monitored with everyday refractometer to ensure proper cutting fluid characteristics. Given the fact that vast quantity of cutting fluid is needed to fill up the tank of a lathe, external system for cutting fluid supply was constructed. It consisted of a 5 litre container in which cutting fluid was be stored. From this container the fluid was transported to cutting zone using Bosh 12V - 3A gear pump with flow rate of Q_v=12 l/min and through a flexible hose. At the end of this hose a nozzle for directing the stream of cutting fluid into the cutting zone was mounted. Above described assembly is graphically presented in Fig. 1.

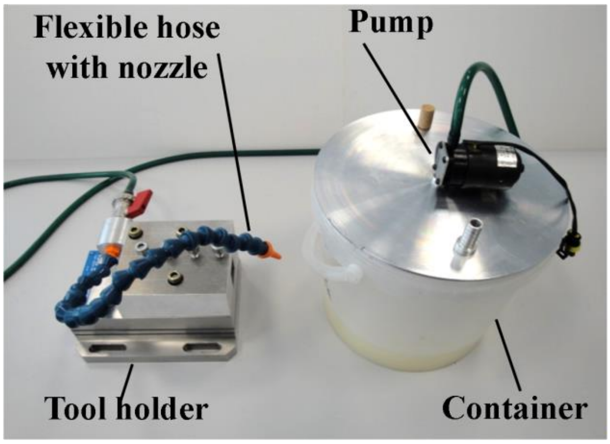


Fig. 1. Apparatus for cutting fluid supply.

2.3 Measurement of electrical consumption of the lathe

One of the main tasks of this research was to monitor the power consumption of the lathe during turning process. For this purpose hi-end power quality analyzer Hioki 3196 was used. During experiments both current and voltage were measured and logged. Current flow was recorded with clamp-on sensor and the actual voltage was registered with voltage cords mounted on the input of the main motor. This solution of monitoring only the main motor consumption was considered to be objective because other electrical devices used negligible amount of power compared to lathe's main motor.

2.4 Kinematics of the experiment

For the purpose of data gathering, measurements were conducted during two types of turning operations which were performed on the lathe – longitudinal and transversal turning. The direction of the cutting tool, during longitudinal turning, was parallel with rotation axis. With this constant chip size and constant value of workpiece diameter was ensured. Transversal turning had one disadvantage and that is because of the perpendicular direction of the cutting tool regarding rotation axis. Result of this was a minor change of the machining diameter, and thus the cutting speed which, according to the experiment results, had no effect on final result. During the realization of the experiment, machining parameters were selected for finishing operations. Selected machining parameters are shown in Table 1.

Table 1. Machining parameters used for experiments.

Parameter	Value		
Depth of cut a_p [mm]	0,5	1	1,5
Cutting speed v_c [m/min]	152		
Feed f [mm/rev]	0,2	0,36	0,56

By combining these three parameters, nine cutting conditions were created. These machining conditions can be seen in Table 2 and Table 3.

3. RESULTS

Power consumption of the lathe during machining, is presented in tables below. Table 2 is showing gathered data of power consumption during longitudinal turning. Accordingly, Table 3 is showing power consumption data for transversal turning method. All thirteen cutting fluids are included in both tables and numbered according to nomenclature in chapter regarding cutting environment.

4. NEURAL NETWORK MODELING

Since all those above mentioned tests were extensive to perform, a cheaper method will be implemented for future prediction of cutting fluid behaviour for given machining parameters [6]. Artificial neural networks were used to learn the pattern of behaviour for every cutting fluid on the basis of these nine parameters combination.

Table 2. Power consumption of the lathe for longitudinal turning.

Experiment No.	**Cutting parameters**		**Power consumption of the lathe [kW]**												
	[mm]	**[mm/rev]**	**CF.1**	**CF.2**	**CF.3**	**CF.4**	**CF.5**	**CF.6**	**CF.7**	**CF.8**	**CF.9**	**CF.10**	**CF.11**	**CF.12**	**CF.13**
1	**a_p=0,5**	**f=0,2**	2,05	2,09	2,09	2,02	2,01	2,03	2,01	2,02	2,03	2,02	2,03	2,01	1,98
2	**a_p=1**	**f=0,2**	2,76	2,76	2,75	2,75	2,74	2,72	2,71	2,84	2,79	2,81	2,79	2,80	2,79
3	**a_p=1,5**	**f=0,2**	3,35	3,37	3,34	3,34	3,33	3,35	3,33	3,42	3,42	3,39	3,38	3,38	3,35
4	**a_p=0,5**	**f=0,36**	2,42	2,43	2,43	2,43	2,59	2,38	2,41	2,43	2,40	2,38	2,40	2,44	2,43
5	**a_p=1**	**f=0,36**	3,59	3,65	3,63	3,64	3,64	3,60	3,59	3,66	3,59	3,66	3,66	3,65	3,66
6	**a_p=1,5**	**f=0,36**	4,53	4,49	4,49	4,49	4,48	4,46	4,41	4,50	4,51	4,52	4,49	4,51	4,50
7	**a_p=0,5**	**f=0,56**	2,82	2,84	2,71	2,82	2,76	2,78	2,80	2,82	2,79	2,77	2,83	2,79	2,79
8	**a_p=1**	**f=0,56**	4,58	4,52	4,52	4,51	4,55	4,54	4,56	4,53	4,50	4,48	4,55	4,59	4,47
9	**a_p=1,5**	**f=0,56**	5,97	5,90	5,93	5,94	5,89	5,85	5,87	5,92	5,92	5,94	5,96	5,88	5,87

Table 3. Power consumption of the lathe for transversal turning.

Experiment No.	Cutting parameters		Power consumption of the lathe [kW]												
	[mm]	[mm/rev]	CF.1	CF.2	CF.3	CF.4	CF.5	CF.6	CF.7	CF.8	CF.9	CF.10	CF.11	CF.12	CF.13
1	a_p=0,5	f=0,2	1,77	1,78	1,87	1,88	1,81	1,88	1,75	1,83	1,85	1,89	1,80	1,78	1,77
2	a_p=1	f=0,2	2,31	2,38	2,43	2,42	2,39	2,36	2,42	2,43	2,44	2,46	2,40	2,39	2,44
3	a_p=1,5	f=0,2	2,75	2,82	2,87	2,82	2,80	2,79	2,79	2,99	2,93	2,87	2,91	2,91	2,92
4	a_p=0,5	f=0,36	2,10	2,12	2,18	2,14	2,13	2,16	2,10	2,05	2,09	2,19	2,09	2,05	2,15
5	a_p=1	f=0,36	2,83	2,91	2,89	2,94	2,95	2,90	2,84	2,93	2,89	2,98	3,08	2,96	2,97
6	a_p=1,5	f=0,36	3,50	3,63	3,67	3,72	3,63	3,66	3,58	3,77	3,85	3,75	3,75	3,76	3,69
7	a_p=0,5	f=0,56	2,54	2,44	2,47	2,50	2,47	2,50	2,48	2,46	2,43	2,51	2,49	2,48	2,41
8	a_p=1	f=0,56	3,42	3,52	3,57	3,63	3,71	3,64	3,59	3,79	3,82	3,59	3,56	3,76	3,70
9	a_p=1,5	f=0,56	4,61	4,36	4,62	4,58	4,63	4,65	4,59	4,63	4,73	4,62	4,81	4,57	4,65

Table 4. Power consumption model for longitudinal turning, generated by artificial neural networks.

Experiment No.	Cutting parameters		Predicted power consumption of lathe [kW]												
	[mm]	[mm/rev]	CF.1	CF.2	CF.3	CF.4	CF.5	CF.6	CF.7	CF.8	CF.9	CF.10	CF.11	CF.12	CF.13
1	a_p=0,5	f=0,2	2,06	2,13	2,10	2,02	2,01	2,04	2,01	2,02	2,16	2,02	2,03	2,01	2,00
2	a_p=1	f=0,2	2,76	2,27	2,79	2,76	2,98	2,72	2,71	2,02	2,03	2,75	2,79	2,83	3,02
3	a_p=1,5	f=0,2	3,35	3,50	3,38	3,34	3,37	3,31	3,33	3,70	3,42	3,39	2,03	4,09	5,53
4	a_p=0,5	f=0,36	2,42	2,43	2,09	2,43	2,59	2,38	2,42	2,02	2,47	2,29	2,40	2,01	2,42
5	a_p=1	f=0,36	3,59	2,39	2,22	3,31	3,64	2,05	3,59	2,08	3,75	4,77	3,68	3,48	3,48
6	a_p=1,5	f=0,36	4,53	5,75	5,38	4,49	4,48	3,60	4,41	4,56	4,52	4,37	4,73	4,78	4,67
7	a_p=0,5	f=0,56	2,81	2,92	2,71	2,82	2,76	2,80	2,80	2,85	2,80	2,69	2,86	3,39	2,85
8	a_p=1	f=0,56	4,57	4,58	4,56	4,50	5,89	5,85	3,69	5,92	4,50	5,41	5,96	4,78	3,33
9	a_p=1,5	f=0,56	4,31	5,81	5,92	5,94	5,89	5,85	5,87	5,92	5,92	5,94	5,96	5,88	5,60

Table 5. Power consumption model for transversal turning, generated by artificial neural networks.

Experiment No.	Cutting parameters		Predicted power consumption of lathe [kW]												
	[mm]	[mm/rev]	CF.1	CF.2	CF.3	CF.4	CF.5	CF.6	CF.7	CF.8	CF.9	CF.10	CF.11	CF.12	CF.13
1	a_p=0,5	f=0,2	1,83	1,81	2,52	1,88	1,92	1,90	1,77	1,90	1,99	2,24	1,83	1,79	1,77
2	a_p=1	f=0,2	1,78	1,90	2,28	2,43	2,50	2,09	2,22	1,92	1,97	2,59	2,41	2,39	2,44
3	a_p=1,5	f=0,2	2,09	2,82	3,17	2,83	3,68	2,70	2,81	2,58	1,88	2,87	2,88	2,91	2,92
4	a_p=0,5	f=0,36	2,06	2,12	2,36	2,53	2,15	2,22	2,10	2,07	1,95	2,20	1,87	2,05	2,16
5	a_p=1	f=0,36	2,86	2,90	3,16	2,93	3,17	2,9	2,84	2,20	2,80	3,35	3,20	2,96	2,97
6	a_p=1,5	f=0,36	3,53	3,62	4,29	4,22	3,61	3,58	3,57	4,51	2,06	3,82	3,73	3,76	3,69
7	a_p=0,5	f=0,56	1,77	2,11	2,09	2,47	2,26	2,64	2,37	2,46	2,52	2,53	1,86	1,79	2,41
8	a_p=1	f=0,56	2,85	3,52	3,63	3,01	3,92	3,65	3,58	3,77	3,81	3,52	3,60	3,76	3,70
9	a_p=1,5	f=0,56	4,54	4,34	4,41	4,58	4,38	4,62	4,57	4,54	4,69	4,53	4,78	4,57	4,65

Since all those above mentioned tests were extensive to perform, a cheaper method will be implemented for future prediction of cutting fluid behaviour for given machining parameters [7]. Artificial neural networks were used to learn the pattern of behaviour for every cutting fluid on the basis of these nine parameters combination. Feed-forward back propagation neural network type was used to discover and learn the pattern of behaviour for each cutting fluid. Number of layers was two and there were ten neurons in each of the layer. Whole neural network was conceived in a way that cutting depth ap and feed rate f were input parameters while power consumption was output parameter. Trained neural network was finally used to predict power consumption on already known data. Table 4 and 5 is containing generated output values for power consumption of the lathe for longitudinal and transversal turning.

Next, the errors are shown in a same manner like power consumptions data. Table 6 and 7 is containing absolute percent errors between ANN modeled and measured power consumption.

Table 6. Percent error of generated ANN model for power consumption for longitudinal turning.

Experiment No.	**Cutting parameters**		**Percent error during power consumption prediction[kW]**												
	[mm]	**[mm/rev]**	**CF.1**	**CF.2**	**CF.3**	**CF.4**	**CF.5**	**CF.6**	**CF.7**	**CF.8**	**CF.9**	**CF.10**	**CF.11**	**CF.12**	**CF.13**
1	**a_p=0,5**	**f=0,2**	0,3	2,15	0,43	0	0	0,41	0	0	6,68	0,26	0,11	0	1,15
2	**a_p=1**	**f=0,2**	0	17,7	1,38	0,46	8,97	0,06	0,13	28,87	27,24	1,97	0,018	0,78	8,13
3	**a_p=1,5**	**f=0,2**	0	3,99	1,31	0,06	1,20	1,17	0,05	8,26	0,01	0,04	39,94	21,07	65,16
4	**a_p=0,5**	**f=0,36**	0	0,21	13,99	0,02	0,02	0,05	0,32	16,87	3,01	4,08	0,07	17,62	0,40
5	**a_p=1**	**f=0,36**	0,01	34,38	38,77	8,93	0,01	43,15	0,02	43,06	4,57	30,43	0,64	4,54	4,87
6	**a_p=1,5**	**f=0,36**	0,02	28,15	19,87	0	0	19,38	0,06	1,38	0,21	3,33	5,27	5,90	3,83
7	**a_p=0,5**	**f=0,56**	0,22	2,82	0,27	0,02	0	0,57	0	1,10	0,35	2,74	1,05	21,67	2,22
8	**a_p=1**	**f=0,56**	0,31	1,33	0,93	0,19	29,45	28,85	19,09	30,67	0,02	20,70	30,95	4,10	25,47
9	**a_p=1,5**	**f=0,56**	27,86	1,45	0,17	0	0	0	0	0	0	0	0,06	0	4,54

Table 7. Percent error of generated ANN model for power consumption for transversal turning.

Experiment No.	**Cutting parameters**		**Percent error during power consumption prediction [kW]**												
	[mm]	**[mm/rev]**	**CF.1**	**CF.2**	**CF.3**	**CF.4**	**CF.5**	**CF.6**	**CF.7**	**CF.8**	**CF.9**	**CF.10**	**CF.11**	**CF.12**	**CF.13**
1	**a_p=0,5**	**f=0,2**	3,63	1,69	34,63	0,02	6,32	0,91	0,95	3,92	7,77	18,63	1,89	0,53	0
2	**a_p=1**	**f=0,2**	23,02	20,09	05,97	0,26	4,43	11,25	8,29	20,95	19,06	5,43	0,58	0	0,18
3	**a_p=1,5**	**f=0,2**	23,88	0,02	10,48	0,27	31,40	3,26	0,76	13,78	35,70	0,12	0,74	0	0
4	**a_p=0,5**	**f=0,36**	1,64	0,19	8,42	18,09	0,75	2,61	0,04	1,16	6,54	0,56	10,72	0	0,26
5	**a_p=1**	**f=0,36**	1,12	0,48	9,47	0,27	7,44	0,14	0,07	24,75	3,23	12,52	4,05	0	0,027
6	**a_p=1,5**	**f=0,36**	0,89	0,18	16,94	13,51	0,57	2,31	0,13	19,61	46,57	2,00	0,48	0	0,15
7	**a_p=0,5**	**f=0,56**	30,27	13,69	15,19	1,344	8,37	5,71	4,28	0,167	3,64	0,92	25,10	27,82	0,06
8	**a_p=1**	**f=0,56**	16,73	0	1,58	17,16	5,73	0,38	0,18	0,52	0,37	1,88	1,10	0	0,05
9	**a_p=1,5**	**f=0,56**	1,47	0,46	4,56	0,05	5,37	0,58	0,50	1,96	1,00	1,91	0,75	0	0,01

5. FRICTION COEFFICIENTS

As it was mentioned before, in this section, friction characteristics of the cutting fluid were measured. Below are presented data regarding friction characteristics of above presented cutting fluids. Aim of this was to achieve more complete picture regarding cutting fluids and their behaviour. During machining friction coefficient is the most informative characteristics of the process [8]. Principle of the experiment is that lubrication effect of the cutting fluid is manifested through thin film which is formed between test piece and rotating ring. Bearing capacity of the cutting fluid can be used for judgment of the lubricating capabilities of the cutting environment. As criteria for evaluation of these characteristics, friction coefficient was chosen. Values of the friction coefficient are dependent on roughness of the sliding surfaces and the material between them. Main task of the tribology is, in this case, to find out the size of wear track which is a result of the contact of the test piece and rotational ring. With this information it will be possible to determine characteristics of the cutting environment.

Rotational ring, in diameter 40 mm, is mounted through mandrel on the clamping system of the lathe. Propulsion of the rotational ring is done by the lathe spindle. Test piece, 5 mm rod in diameter, is firmly mounted on the rocker and by the simple lever is pressed against the rotational ring. Container is mounted on the holder with ability to freely rotate. Holder is then mounted onto the dynamometer which is attached on the cross slide of the lathe. Schematic of the device assembly is shown in Fig. 2. Actual footage of the device is shown in Fig. 3.

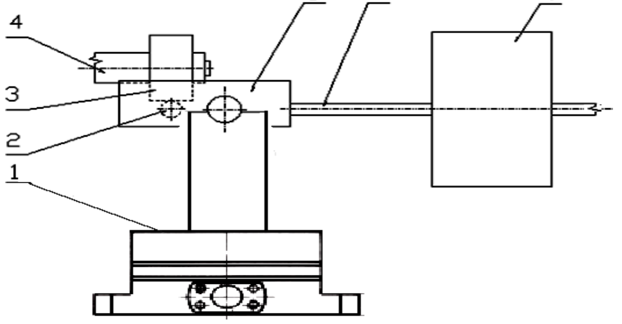
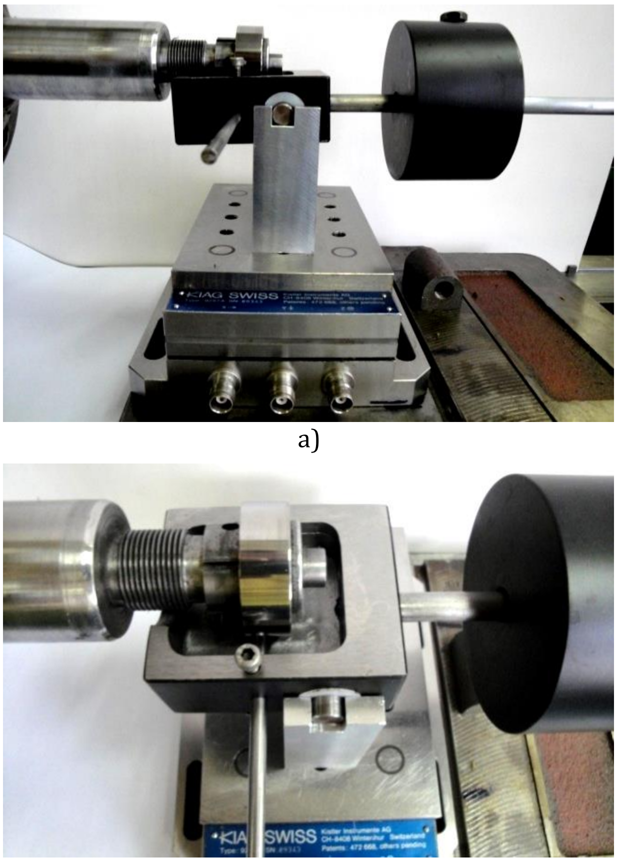


Fig. 2. Schematic interpretation of constructed tribometer: 1–dynamometer, 2–test piece, 3–rotational ring, 4–mandrel, 5–container, 6–arm of the rocker, 7–adjustable weight.



a)

b)

Fig. 3. Tribometer mounted on the lathe, a) side view, b) top view.

Radial dimensional error of the rotational ring has to be as small as possible to avoid additional dynamic load which would result in increasing of the friction. Because of this, rotational ring was fine grinded when mounted on the lathe with grindstone in place of the cutting tool.

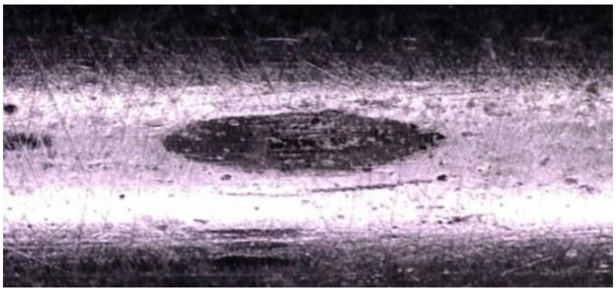


Fig. 4. Wear track on test piece surface.

For the purpose of experiment C45 steel rod with 5 mm in diameter and length 100 mm was used as a test piece. In the first phase of the experiment, wear track on the test piece was made (Fig. 4). To make this track a load of F_n=300N was set and length of track was determined based on the dependency of increase of track length and length of ring in the test piece. Size of the wear track has been measured with Smartscope MVP 200 microscope. Test conditions for friction factor measurements are shown in Table 8.

Table 8. Experimental parameters for measurements of the friction factor.

Parameter	**Value**
Cutting environment	Cutting fluid No. 8
Spindle speed *n* [rev/min]	200
Normal force F_n [N]	300
Material of the ring	HSS DIN S12-1-4-5
Material of the test piece	Steel C45

Table 9. Values of tangential force F_t and calculated values of friction coefficient f_t for monitored cutting fluids.

Cutting fluid No.	**F_t [N]**	**f_t**
CF.1	-40,795055	0,407951
CF.2	-26,740433	0,267404
CF.3	-23,866435	0,238664
CF.4	-43,846772	0,438468
CF.5	-33,760549	0,337605
CF.6	-32,024988	0,32025
CF.7	-23,164837	0,231648
CF.8	-31,237965	0,31238
CF.9	-27,695846	0,276958
CF.10	-32,737425	0,327374
CF.11	-47,903293	0,479033
CF.12	-31,879182	0,318792
CF.13	-46,450293	0,464503

In the second phase of the experiment a friction force was monitored. Important factor which have to comply was total absence of build-up phenomena on both contact surfaces. To avoid this normal force was set to be F_n = 100N and contact pressure was lowered enough to enable the forming of the lubricating film between two surfaces. Intensity of the friction force was recorded with dynamometer Kistler 9257. With recorded friction force F_t and known normal force F_n=100N the friction coefficient can be calculated from Eq. 1:

$$f = \frac{F_t}{F_n} \qquad 1)$$

where F_t – is the friction force [N] and F_n – is the normal force [N] between the rotational ring and test piece. Friction coefficient is the measure of lubricating properties of certain cutting fluid. The logic behind this is that the smaller the friction coefficient the better the lubricating effect is. Values for measured friction forces and calculated friction coefficients are shown in Table 9.

6. CONCLUSION

In this paper various cutting fluids and their influence on lathe power consumption was investigated. A major difference of influence was discovered among cutting fluids while using same machining conditions. Also within this paper the ANN model was created and tested if it could be used for prediction of power consumption for particular cutting fluid. Since experimental data was scarce to begin with, the ANN model was tested on existing data and therefore it couldn't present the true image of modeled network capability in prediction. However, generated results showed potential in this area of application. For future investigations in this field, more experimental data should be obtained and at the end ANN should be tested on unknown data to get the real potential of their capabilities.

Regarding friction factor in cutting fluids, vast differences were observed among couple of fluids. For example cutting fluid CF.7 has the smallest friction coefficient which would make her the most desired from the point of lubricating capabilities. On the other hand cutting fluid CF.11 has more than twice the value of friction coefficient when compared to mentioned CF.7. To conclude, the friction coefficient of the cutting fluid is a valuable data when it comes to choosing the adequate cutting fluid.

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