

OPTIMIZATION OF CUTTING PARAMETERS OF TURNING OPERATION WITH VORTEX TUBE COOLING SYSTEM USING ARTIFICIAL NEURAL NETWORK METHOD

PhD. Onat A.¹, M.Sc. Yüksel S.¹, PhD. Hartomacıoğlu S.¹

Marmara University, Faculty of Technology, Department of Mechanical Engineering¹

ayhanonat@marmara.edu.tr

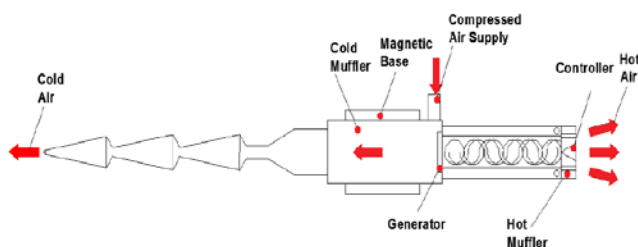
Abstract: Controlling the heat during cutting operations are an important factor in improving the quality of the product and performance of the machining. For controlling the heat, there are a lot of methods. One of this is Vortex Tube Cooling System. In this study, the Vortex tube cooling system was used to control heat during the turning operation. In the design of experiment, cutting speed, cooling temperature, feed rate, and cutting tool corner radius were selected as input parameters. Surface roughness and cutting force was selected as output parameters. The input and output parameters were modeled by using Artificial Neural Network, the results of experiment were optimized.

Keywords: VORTEX COOLING SYSTEM, VORTEX TUBE, ARTIFICIAL NETWORK METHOD, SURFACE ROUGHNESS, CUTTING PARAMETERS

1. Introduction

During the machining of a work piece, most of the energy is transformed to heat due to the shear stresses. For this reason the heat is an important factor in improving the quality of the product and performance of the machining. Although, the use of the cutting liquids improves the cooling performance, it increases the cost of production and has really harmful effect on environment. Therefore, it is necessary to find different cooling techniques gradually increases in recent years.

One of such cooling methods is the vortex tube cooling system. The vortex tube was discovered in 1930 by French physicist Georges Ranque. Vortex tube is a very simple, compact, and quiet mechanical device without any moving components, which can separate an incoming compressed gas stream of uniform temperature into two streams, one warmer than the inlet stream and the other colder than the inlet stream [1]. Such separation of the gaseous fluid stream into two different streams of higher and lower temperatures is referred to as temperature (energy) separation effect. Ranque invented the vortex tube which occurred about the energy separation. Subsequently Hilsch published systematic experimental results of this effect. Hilsch suggested that the expansion of air from high pressure near the wall to low pressure near the axis generates a velocity gradient in radial direction which results in transfer of kinetic energy by the viscous force from the inner fluid layers to the outer fluid layers [2-3]. A schematic view



of vortex tube is shown in Fig 1.

Fig. 1. Schematic view of vortex tube [1]

A Ranque-Hilsch Vortex Tube (RHVT) consists of one or more inlet nozzles, a vortex chamber, a cold-end orifice, a hot-end control valve and a tube. Special internal configurations of the designed vortex chamber combine effects of pressure and accelerated air, leading to a high rate of rotation [4]. Vortex Tubes are available in a wide range of sizes to meet the needs of many process and spot cooling applications. The vortex tube can be applied to many industrial applications such as cooling system of CNC machines, refrigerators, cooling suits, heating process, etc. Since, it has no moving parts, it does not break or wear and therefore it requires little maintenance [5].

Chilled air, generated by a vortex tube (VT), has been investigated as an alternative cooling method for efficient heat dissipation in machining [6]. Yüksel and Onat concluded that temperature changes obtained through the use of vortex tube have a very slight effect on the cutting force in response surface methodology [1]. Aronson tested VTs in high-speed drilling and reported that VT cooling may improve the tool life by ten times [7]. Liu and Hou applied VT cooling in steel turning and claimed that VT cooling may reduce crater wear, flank wear, and the flank wear rate [8]. Choi et al. reported that VT cooling is capable of reducing surface roughness and generating compressive residual stresses at the workpiece surface in cylindrical grinding [3]. Nguyen and Zhang combined VT cooling and oil mist during surface grinding and demonstrated that a small amount of vegetable oil adds lubrication to cold-air cooling and improves the material removal rate under identical part quality constraints [9].

2. Materials and Method

In the experimental study, the turning cutting tools with different corner radius were used. The Vortex tube system were used as cooling system in turning operations. The material of 42CrMo4 was used as workpiece part. The material was machined by using CNC Turning machine with two axes. In the experimental design, feed rate (f , mm/rev), cutting speed (V , m/min), cooling temperature (T , °C) and corner Radius of cutting tool (r , mm) were used input parameters. Surface roughness (R_a , μm) and cutting force (F , N) values were used as output parameter in experimental design. Depth of cut, diameter and length of workpiece part were 2.5 mm, 50 mm, and 120 mm, respectively. The input variable of experimental design and their levels were listed in Table 1.

Table 1. The input variable of experimental design and their levels

Factors	Min	Mean	Max
A: Feed rate (mm/rev)	0.15	0.25	0.35
B: Cutting speed (V, m/min)	100	250	400
C: Cooling temperature (T, °C)	-4	-8	20
D: Corner radius of cutting tool (r, mm)	0.4	0.8	1.2

Fractional experimental design method was used instead of full factorial design to save time of experimental study and for sustainability. Central composite design method and face centered as alpha value were used for fractional experimental design. Fractional experimental table was prepared using minimum, maximum and mean value of input factors of experiments using statistical software. 34 experiments were determined using fractional experimental design and the experiments were carried out under these conditions. After the obtaining results of experiments, Artificial Neural Network (ANN) approach developed with the learning and decision-making abilities of the human brain was used to modelled the experimental results and new data sets were created and their results were predicted using the ANN structure. The Surface roughness and cutting forces value predicted by ANN approach were optimized by using Grey Relational Analysis (GRA), and The experiments were ranked using 'Smaller-is-better' approach.

Basic step of ANN method; 1) Normalization, 2) Separation of two groups of data set as training and testing, 3) Training, 4) Testing, 5) Prediction new results of new data set. In the ANN step, Neurosolutions for Excel software was used. First step of ANN process, the data set was normalized from 0 to 1. After, rows of data set were randomly sorted, and the data was divided into two groups; 1) training group (75%) and 2) testing group (%25). In the ANN procedure, training procedure is about finding the network structure that gives the smallest error. Multilayer perceptron (MLP) is the powerful topology of the ANN structures. In this study, MLP was used. In the MLP structure, there are two layer; 1) input layer, 2) hidden layer, and 3) output layer. Input layer contains artificial neurons up to the number of experiment input parameters, output layer contains artificial neurons up to the number of experiment output parameters. The ANN structure was given in Figure 2.

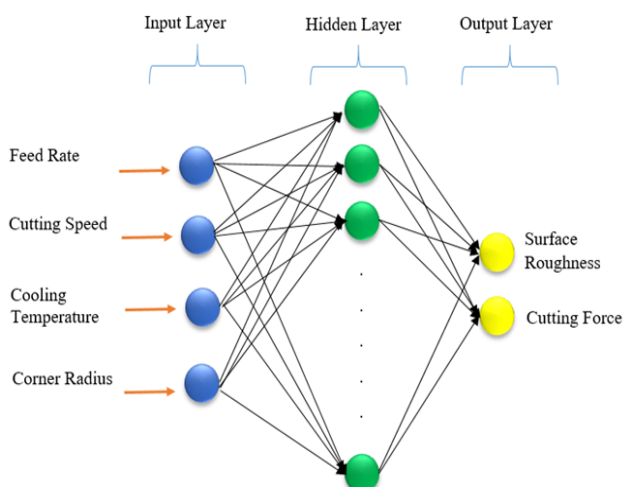


Fig. 2. Developed ANN structure

In the training step, the number of hidden layer neurons was found by trial and error method. 60 000 epochs, range of 2-60 neurons of hidden layer, and 'Momentum (0.7) as learning rule were used in training. Each network type was trained by 3 times and standard deviation values were calculated. Mean Square Error (MSE) was used as error type. The type of ANN that gives the lowest MSE value in the training was determined and testing operation was performed using this optimal network structure. In the test operation, Mean Absolute Error (MAE) was used as error value and the error value below 10% indicated that the network is successful.

After the obtaining optimal ANN structure for results of experiments, results of new data set were predicted by using optimal ANN structure. For this, new value of input parameters was assigned and listed in Table 2.

Table 2. New value of input parameters

Levels	Input Factors			
	Feed Rate (F, mm/rev)	Cutting Speed (V, m/min)	Cooling Temperature (T, °C)	Corner Radius (R, mm)
1	0.10	50	-8	0.20
2	0.15	100	-4	0.40
3	0.20	150	0	0.60
4	0.25	200	4	0.80
5	0.30	250	8	1.00
6	0.35	300	12	1.20
7	0.40	350	16	1.40
8	0.45	400	20	1.60

In this step, full factorial experimental design method was used and total number of experiments was 4096. After the new data set was normalized, new results of the data set were predicted using optimal ANN structure. 4096 results were sorted by Grey Relational Analysis (GRA) method and the results were optimized. In the GRA step, factors of surface roughness and cutting forces were optimized by using 'Smaller-is-better' approach.

3. Results and Discussion

The surface roughness and cutting force values which is calculated in the aftermath of experimental operations are indicated in Table 1. Optimal ANN structure is found by taking experimental results into the phases of ANN. The level of hidden layer neurons in the ANN training phase was found by testing at 60 000 iterations and 2-60 neurons. Change chart of MSE value depending on the hidden layer neuron number is given in figure 3 After training step, the structure with least fail is the one with 30 network type hidden layer and 60 000 iterations. Momentum (0.7) as learning rule and multilayer perceptron (MLP) as network topology is used in the structure. Testing is done by using a test group via this improved ANN structure. A result of testing is given in figure 4. Actual numerical values are obtained by subjecting the data reversed normalizing process and percental error values are calculated and listed in Table 3.

Table 3 Results of experiments

F [mm/rev]	V[m/min]	T, [°C]	R, [mm]	Ra, [μm]	F [N]
0.15	100	-4	0.4	1.77	483.78
0.35	100	-4	0.4	4.82	932.37
0.15	400	-4	0.4	1.62	445.23
0.35	400	-4	0.4	5.30	878.17
0.15	100	20	0.4	1.45	477.11
0.35	100	20	0.4	5.23	936.12
0.15	400	20	0.4	1.67	444.04
0.35	400	20	0.4	4.98	874.16
0.15	100	-4	1.2	1.43	522.28
0.35	100	-4	1.2	3.24	933.78
0.15	400	-4	1.2	0.78	473.12
0.35	400	-4	1.2	2.82	903.39
0.15	100	20	1.2	0.85	475.06
0.35	100	20	1.2	3.20	943.90
0.15	400	20	1.2	1.08	523.06
0.35	400	20	1.2	2.49	914.54
0.15	250	8	0.8	1.39	530.23
0.35	250	8	0.8	3.71	922.49
0.25	100	8	0.8	2.42	746.34
0.25	400	8	0.8	2.34	699.89
0.25	250	-4	0.8	2.00	717.24
0.25	250	20	0.8	2.24	689.94
0.25	250	8	0.4	3.55	640.37
0.25	250	8	1.2	1.85	696.11
0.25	250	8	0.8	2.26	697.04
0.25	250	8	0.8	2.11	697.26
0.25	250	8	0.8	2.09	702.06
0.25	250	8	0.8	2.06	704.28
0.25	250	8	0.8	2.34	722.09
0.25	250	8	0.8	2.22	718.02
0.25	250	8	0.8	2.18	712.11
0.15	100	20	1.2	1.31	521.35
0.15	400	20	1.2	0.61	491.53
0.35	400	20	0.4	5.16	865.41

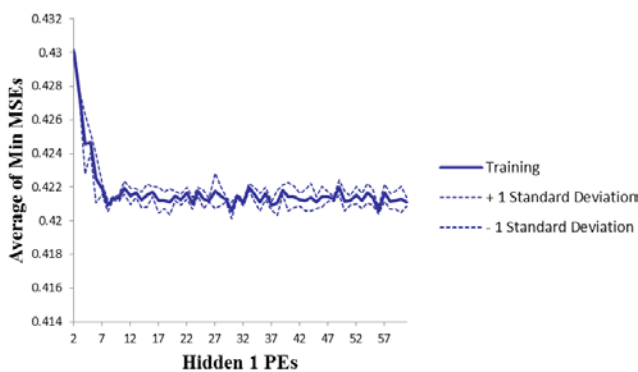


Fig. 3. The effect of changing of neuron number of hidden layer on MSE

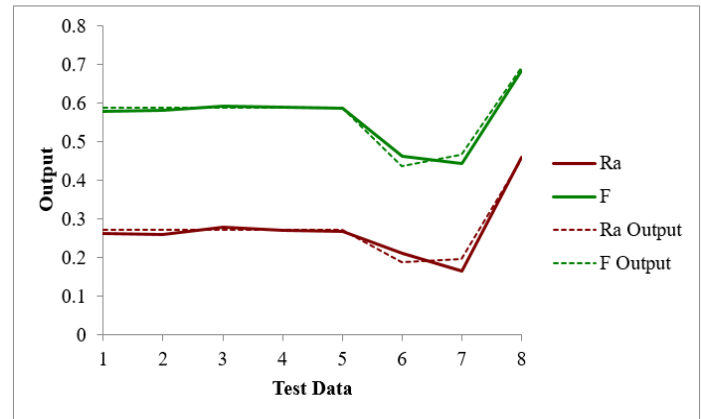


Fig. 4. The Results of Test Operation

The correlation coefficient for test operation was calculated as 0.98. Mean Percentage error for surface roughness and cutting forces for test operations were calculated as 5.4% and 1.92%, respectively. As a results of training step, tests step was sufficient and the ANN structure could be used to predict the results of new experimental data.

In this step, full factorial experimental design method was used and total number of experiments was 4096. After the new data set was normalized between 0 and 1 values, new results of the data set were predicted using optimal ANN structure. Especially the gray relational analysis method is used as multi criterial selection method and has successful applications in many areas. Especially used in listings of experimental results. In the GRA step, the experimental results were optimized by using ‘Smaller-is-better’ approach. Gray Relational Analysis procedure is given in reference [10]. After sorting, the best 10 and worst 10 experimental conditions and gray relational values are given in the Table 4 and Table 5.

Table 4. Optimal experimental conditions and their results

Exp. Num.	F	V	T	R	Ra	F	GRD
456	0.1	400	-8	1.6	0.8380	458.3209	1.9525
455	0.1	400	-8	1.4	0.8430	458.9769	1.9479
464	0.1	400	-4	1.6	0.8368	460.6817	1.9445
454	0.1	400	-8	1.2	0.8517	459.3720	1.9426
463	0.1	400	-4	1.4	0.8411	461.2544	1.9405
392	0.1	350	-8	1.6	0.8554	460.0920	1.9383
453	0.1	400	-8	1	0.8702	458.4215	1.9379
462	0.1	400	-4	1.2	0.8499	461.5323	1.9356
391	0.1	350	-8	1.4	0.8612	460.7935	1.9332
452	0.1	400	-8	0.8	0.9195	454.1414	1.9327

As shown to table the experimental parameters depending on the best surface roughness and the lowest cutting force, 0.1 mm/rev feed rate, 400 m/min cutting speed, -8 °C cooling temperature and 1.6mm corner radius value. The experimental result value is shown the best surface roughness value 0.83 μm, the lowest cutting force values is 458.32N.

Table 5. The worst experimental conditions and their results

Exp. Num.	F	V	T	r	Ra	F	GRD
3705	0.45	100	20	0.2	5.29	943.54	0.6668
3641	0.45	50	20	0.2	5.29	943.59	0.6668
3697	0.45	100	16	0.2	5.29	943.54	0.6668
3761	0.45	150	16	0.2	5.29	943.45	0.6668
3769	0.45	150	20	0.2	5.29	943.44	0.6668
3753	0.45	150	12	0.2	5.29	943.46	0.6668
3633	0.45	50	16	0.2	5.29	943.59	0.6668
3689	0.45	100	12	0.2	5.29	943.54	0.6669
3817	0.45	200	12	0.2	5.29	943.30	0.6669
3825	0.45	200	16	0.2	5.29	943.29	0.6669

In this present study, we would like to make a detailed search on applying of vortex tube cooling system in turning, modeling of the results via usage of ANN method and optimizing the results via GRA method. After determining of experimental parameters, an experiment chart is prepared by using fractional experimental design method, experiments are made in the highlights of this table. Optimum ANN model is improved for experimental results and result predictions are made for new data group by using new ANN structure. There are two parameters, surface roughness value and cutting forces, as out parameters. According to one of the full factorial decision making methods, GRA structure, and these two out parameters 4096 results were gotten via "small is better approach". The best and the worst 10 experimental conditions are indicated in the table 4 and table 5.

The best experimental parameters depending on surface roughness and cutting force, 0.1 mm/rev feed rate, 400 m/min cutting speed, -8 °C cooling temperature and 1.6 mm corner radius value. The experimental result value are shown the best surface roughness value 0.83 µm, the lowest cutting force values is 458N. The worst experimental parameters values are 0.45 mm/rev feed rate, 100 m/min cutting speed, 20 °C cooling temperature and 0.2 mm corner radius value are shown, the worst surface roughness value 5.29 µm, the highest cutting force values is 943 N. When prediction results are evaluated; it is determined that increase of cutting speed will cause decrease in cutting force and surface roughness values, increase of feed rate and increase of cooling temperature will cause an increase over them.

It is noticed that fractional experimental design +ANN+GRA methodologies used at prediction and optimizing steps gave successful results, the percental error values at testing step via ANN structure is quietly under the acceptable limit 10% (for surface roughness 5,50%, for cutting force 2,92%), 4096 experimental match predicted via GRA method could be successfully listed with "smaller-is better" approach.

4. Conclusion

When the results of experimental study and optimization step were evaluated;

1. The cooling system with Vortex tube will provide significant advantages for surface roughness and cutting force on turning operations
2. For the turning operations, the hybrid model of Fractional Experimental Design (FED)-Artificial Neural Networks (ANN)- Grey Relational Analysis GRA was developed
3. The FED-ANN-GRA hybrid model could be used successfully in the optimization of turning operation's parameters

4. Using of the hybrid model in the experimental studies will lead to decrease research and development time
5. Using the hybrid model in the experimental studies provide significant advantages sustainability and costs of product development process.

5. References

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