

## Investigation of the Relationship between Vibration, Cutting Forces and Tool Wear During the Processing of Inconel 718 Super Alloy under Coolant Pressure Jet-Assisted Turning with Variance Analysis

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### ABSTRACT

In this study, cutter vibrations, wear conditions and cutting forces are observed during jet-assisted turning under coolant pressure conditions. Inconel 718 material is used as a thread. The data generated at cutting time is saved to a computer. Relationship between coolant pressure, vibration, tool wear and cutting forces is investigated with variance analysis. In variance analysis, Root Mean Square of vibration (vibration\_RMS), RMS values of cutting forces and tool wear are chosen as dependent variables, and coolant pressure is chosen as independent variable. As a result of the analysis, it is found that the effect of coolant pressure on vibration is very important ( $P<0.01$ ) on cutting forces and tool wear. Duncan multiple comparison test is applied after analysis of variance. According to the Duncan test results, it is observed that 100 bar cutting tests are the optimum tests under coolant pressure.

**Keywords:** Turning with high pressure jet-assisted cooling, tool wear, cutting tool vibration, analysis of variance

## Yüksek Soğutma Sıvısı Basıncı Altında Inconel 718 Süper Alaşımın İşlenmesi Sırasındaki Titreşim, Kesici Kuvvetler ve Takım Aşınması Arasındaki İlişkinin Varyans Analiziyle İncelenmesi

### ÖZ

Bu çalışmada, soğutma sıvısı basıncı altındaki tornalama koşullarında kesici titreşimleri, aşınma koşulları ve kesici kuvvetleri izlenmiştir. İş malzemesi olarak Inconel 718 kullanılmıştır. Kesme anında oluşan veriler bilgisayara kaydedilmiştir. Soğutma sıvısı basıncı ile titreşim, takım aşınması ve kesici kuvvetler arasındaki ilişki Varyans (ANOVA) analizi yöntemi ile incelenmiştir. Varyans analizinde titreşim\_RMS (Root Mean Square)'i, kesici kuvvetlerin RMS değerleri ve takım aşınması bağımlı değişken, soğutma sıvısı basıncı ise bağımsız değişken (faktör) olarak seçilmiştir. Analiz sonucunda soğutma sıvısı basıncının titreşim, kesici kuvvetler ve takım aşınması üzerine etkisinin çok önemli olduğu tespit edilmiştir ( $P<0.01$ ). Varyans analizinden sonra Duncan çoklu karşılaştırma testi uygulanmıştır. Duncan testi sonuçlarına göre sınıflama yapıldığında ise 100 bar'lık kesme deneylerinin en uygun soğutma sıvısı basıncı altında yapılan deneyler olduğu görülmüştür.

**Anahtar Kelimeler:** Soğutma sıvısı altında kesim, takım aşınması, takım titreşimi, varyans analizi

## INTRODUCTION

Machining is one of the most important methods of today's manufacturing technologies and remains current. One of the most important raw materials of machining is Nickel-based super alloys. Nickel-based superalloys have had a great use recently in the aviation industry. It is also used in industrial gas turbines, spacecraft, rocket engines, nuclear reactors, submarines, steam generating plants, petrochemical devices and other heat resistant applications. In these respects, it is important to know the most suitable machining parameters for a super alloy such as Inconel 718. In this study, it is aimed to determine suitable parameters for Inconel 718 super alloy.

Hard-to-cut materials are widely used in many engineering applications. These materials are preferred in automotive and aviation designs due to their properties. One of these materials is Inconel 718. Hegab and Kishawy (2018) studied the determination of the appropriate values of the cooling and lubrication processes during the turning process of Inconel 718 material. It is observed that the processing performance of the Inconel 718 material is enhanced by nanofluids. Alvarez et al. (2017) measured the temperature values with a sensor during the processing of the Inconel 718 material. The temperature value measured in their study is in the range of 250-1200 centigrade degrees. These values are then estimated by developing a mathematical model.

Chuangwen et al. (2018) and Prasad and Babu (2017) reviews the importance of relationship between vibration, tool wear, cutting forces and surface roughness during material processing. Correlations among these are tried to be calculate by processing different materials and measuring result values. For estimation of these results, Prasad and Babu (2017) performs some simulation studies. Kindi et al. (2018) and Yilmaz et al. (2014) generates these studies in both jet-assisted turning and milling operations. They use variance analysis methods to calculate the appropriate parameters in milling operations. Lotfi et al. (2018) utilize the ultrasonic data that is one of the measurements used in variance analysis. The data obtained by ultrasonic measurements are interpreted by digital processing techniques. Güngör (2011) and Bhuiyan and Choudhury (2015) reports that RMS calculation can be used in the evaluation and interpretation of obtained signals, because RMS calculation is a reliable method for interpreting sinus amplitude signals.

The following steps are applied to calculate the RMS value of a signal as discrete (digital):

- The amplitude values are taken at a specific sampling time for a period of signal

- Sum of the squares of these values are calculated. This result is divided by the number of samples taken
- The square root of this section is taken.

$$x_{rms} = \sqrt{\frac{1}{n}(X_1^2 + X_2^2 + X_3^2 + X_4^2 \dots + X_n^2)} \quad (1)$$

The higher the measurement accuracy is obtained with more frequent sampling when RMS value is calculated by this method.

While the RMS value of a signal is continuously (analogue) calculated, measurement of the effective value ( $U_{eff}$ ) of the voltage ( $u(t)$ ) in the alternative and optional form of electrical signals has great importance in automation and control technologies. Germer (2001) calculates  $X_{rms}$  as in equation 2 in the effective value measurement systems.

$$x_{rms} = \sqrt{\frac{1}{T} \int_0^T x^2(t) dt} \quad (2)$$

Equation 1.1 is used to measure continuous signals. There is a discrete-time signal processing in the calculation method. A sampling frequency ( $f_s$ ) can be mentioned in discrete time signal processing. This sampling frequency should be at least twice the input frequency ( $f_i$ ) according to Nyquist's theorem (equation 3). Petrović (2015) points out that sampling frequency should be kept as high as possible to make the measurement results more precise.

$$f_s \geq 2f_i \quad (3)$$

In this study, equation 1 is used to calculate the digital equivalent at each point.

Paul et al. (2016) specifies that modified hard materials are difficult to process in a pure, dry environment during material processing with a jet-assisted turning. For this reason, Yan et al. (2016) and Revankara et al. (2014) aims to improve the cutting process by using high pressure coolant during material processing. The purpose of using coolant is to reduce cutting temperatures and prevent surface corrosion. Güngör (2011) and Kamruzaman and Dhar (2009) tries to examine proper pressure value by observing vibration during processing under coolant pressure and changes in cutting force and tool wear.

Özel et al. (2005) examines cutting edge geometry, thread hardness, cutting speed, surface roughness and strength during hard turns of steel materials such as AISI H13 while machining. Özel and Zeren (2007) indicates that the sharp edges during material processing at high speeds could cause temperatures and stresses by Finite

Element Method (FEM). Güllü et al. (2008) demonstrates the great importance of the processing parameters due to the hardness of the Inconel 718 inside the super alloy materials. Xavior et al. (2017) performs variance analyzes for cutting edge selection and cutting force parameters during processing of this super alloy.

Güngör (2011), Ramakrishnana and Karunamoorthy (2008), Lohithaksha et al. (2013), and Salimasli and Rafighi (2016) have developed simulations related to the processing difficulties of Inconel 718 material. These simulations include methods such as ANN, Taguchi-based graphical analysis and Fuzzy logic.

## MATERIAL AND METHOD

The data presented in this study are obtained at the cutting speed of 50 m/min, the feed rate of 0.15 mm/cycle and the cutting depth of 2.5 mm in CNC jet-assisted turning processing of Inconel 718 super alloy material. Keeping these parameters constant, three different parameters are used by the coolant pressure. These are coolant pressure values of 6, 100 and 300 bar. The CNC jet-assisted turning which the tests are performed is shown in Figure 1.

Values are recorded to the computer with Cut-Pro program and interpreted in Matlab program. PCB Piezotronic model 353B31 (Figure 2) is used as a vibration sensor.

A “Kistler 9257 A” model dynamometer (Figure 3) is used to measure the cutting force signals.

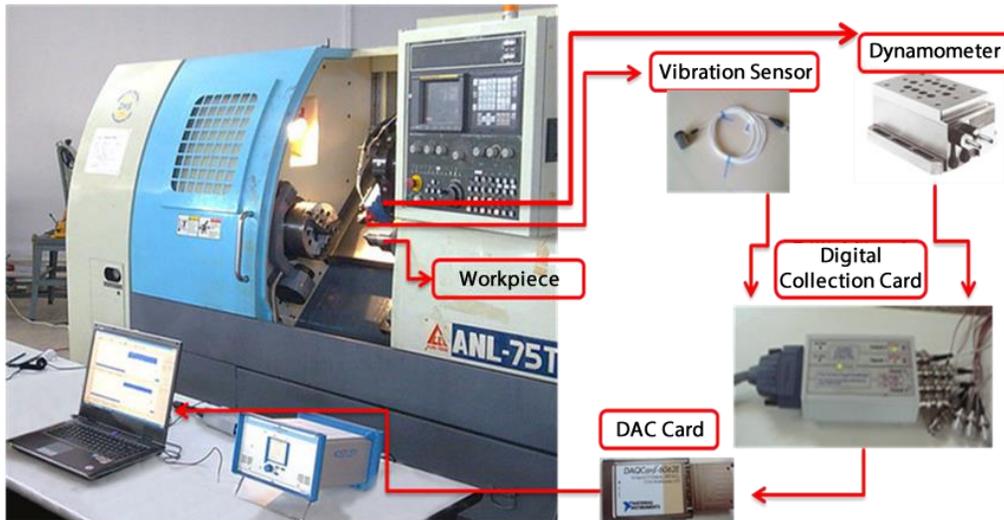
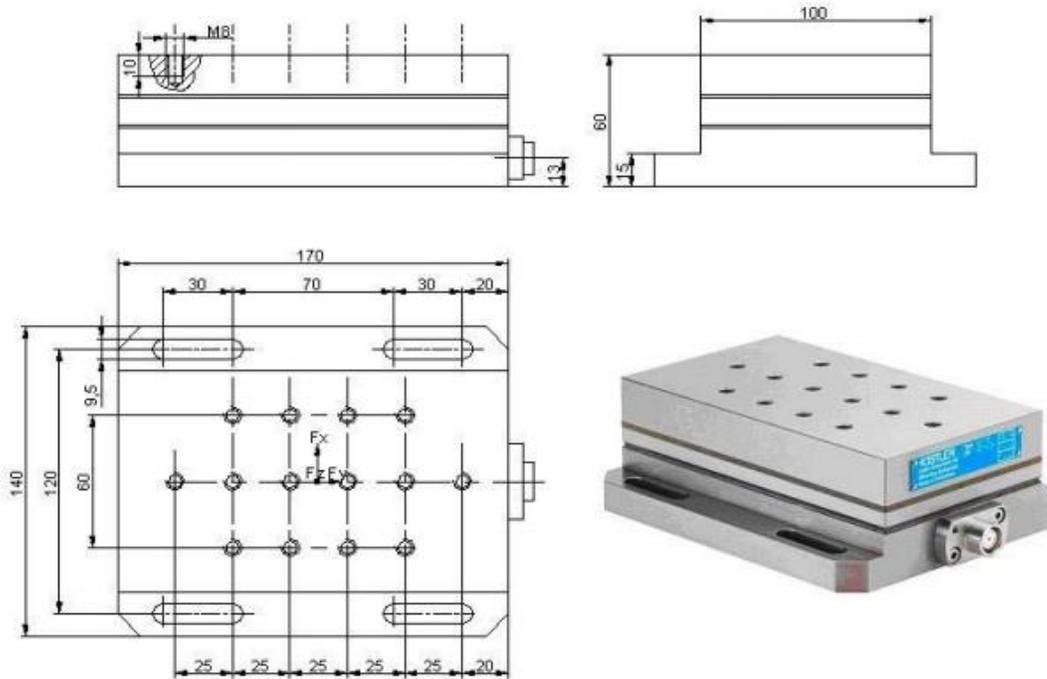


Figure 1. CNC jet-assisted turning



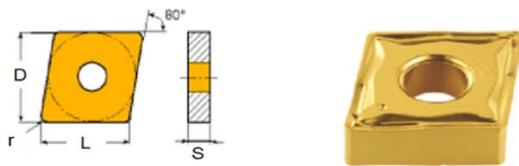
Figure 2. PCB 353B31 vibration sensor



**Figure 3.** Kistler 9257-A model dynamometer

The wear values of the cutting tool are measured under a microscope and are determined with the Motic program.

“SECO Jet Stream” is preferred as cutting tool. The reason for preferring tools from the Jet Stream 26 system in this study is their ability to respond to maximum pressure of 350 bar. The cutting edge used in this study is shown in Figure 4 and geometric dimensions of cutting edge is shown in Table 1.

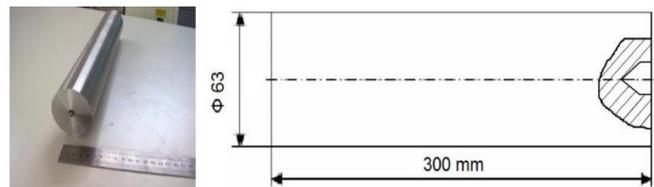


**Figure 4.** Cutting edge used in the experiments

**Table 1.** Geometric dimensions of cutting edge

Presentation (ISO)	Class	D	L	S	R
CNMG 120408-MR4	CP250	12.7	12.9	4.76	0.8

“Inconel 718” is used as work piece. The dimensions of the material are shown in Figure 5. In addition, the chemical composition of the material is given in Table 2 and its mechanical properties are shown in Table 3.



**Figure 5.** Geometrical features of the Inconel 718 material used in the experiments

**Table 2.** Chemical composition of Inconel 718 (% weight)

Ni	Cr	Co	Mo	Nb+Ta	Mn	C	Si	Ti	Al	Fe
53.37	18.37	0.23	3.04	5.34	0.08	0.04	0.08	0.98	0.5	17.8

**Table 3.** Mechanical properties of Inconel 718

Tensile Strength (MPa)	Yield Strength (MPa)	Elastic Mod-ule (GPa)	Hard-ness (HRc)	Density (g/cm3)	Melting Point (0C)	Heat conduc-tivity (W/mK)
1310	1110	206	52	8.19	1300	11.2

T is tool life (minute), V is cutting speed (m/min) and n is the tool base and it depends on factors such as tool material, workpiece material, machining conditions, feed amount or depth of cut, tool geometry and coolant. Thus;

$$T.V^k = C = \text{Constant} \quad (4)$$

C is the cutting speed corresponding to one-minute life, which is dependent on the tool and the part material. As the cutting speed is increases in equation (4), it is seen that tool life decreases.

It is analyzed whether there is a relationship between coolant pressure and vibration, cutting forces (vertical, horizontal) and tool wear with variance analysis (using SPSS statistical program). In variance analysis, vibration\_RMS, RMS values of cutting forces and tool wear are chosen as dependent variables, and coolant pressure is chosen as independent variable. It is found that the effect of coolant pressure on vibration is very important ( $P < 0.01$ ). Duncan multiple comparison test is applied after analysis of variance.

The results of the variance analysis between vibration and coolant pressure are shown in Table 4.

**Table 4.** Vibration\_RMS

Duncan <sup>a,b,c</sup>			
Pressure (bar)	N (test)	Subset (m/s <sup>2</sup> )	
		1	2
100,00	12	1.6708	
6,00	13		4.7240
300,00	7		5.1229
Sig.		1.000	0.259

According to Duncan test results in table 4, the lowest mean vibration\_RMS is 1.67 m/s<sup>2</sup> as a result of the 100 bar cutting tests, while it is calculated as 4.72 m/s<sup>2</sup> and 5.13 m/s<sup>2</sup> with 4 and 6 bar cutting tests respectively and the difference between these vibration\_RMS' are found to be insignificant. The error margin is calculated 0.593. In the light of these data; it can be said that there is no difference in vibration which is observed during cutting

of the material under 6 or 300 bar pressure. It is determined that the most ideal cutting process is under the pressure of 100 bar coolant.

The results of variance analysis between vertical cutting force and coolant pressure are shown in Table 5.

**Table 5.** Vertical cutting force RMS

Duncan <sup>a,b,c</sup>			
Pressure (bar)	N (test)	Subset (Newton)	
		1	2
300,00	7	297.3700	
100,00	12	337.4342	
6,00	13		676.3184
Sig.		0.529	1.000

The results of variance analysis between horizontal cutting force and coolant pressure are shown in Table 6.

**Table 6.** Horizontal cutting force RMS

Duncan <sup>a,b,c</sup>			
Pressure (bar)	N	Subset (Newton)	
		1	2
300,00	7	275.6029	
100,00	12	313.3642	
6,00	13		653.1148
Sig.		0.553	1.000

As a result of the analysis, the effect of coolant pressure on cutting forces is found to be very important ( $P < 0.01$ ). Duncan multiple comparison test is applied after variance analysis.

According to the Duncan test results which are shown in table 6, the lowest average cutting forces obtained from 100 and 300 bar shear tests are 275 N - 337 N and these values are included in the same classification. The force applied during the cutting process under coolant at 6 bar pressure is calculated as 653 N - 676 N which is almost two times of other tests. In the light of these data, no

difference is observed in the cutting forces during cutting of the Inconel 718 material under 100 or 300 bar pressure. After tests under three different pressure conditions, it is determined that the maximum cutting force is applied at 6 bar coolant pressure.

The results of variance analysis between tool wear and coolant pressure are shown in Table 7.

**Table 7.** Tool wear

Duncan <sup>a,b,c</sup>			
Pressure (bar)	N	Subset ( $\mu\text{m}$ )	
		1	2
100,00	12	142.0833	
300,00	7	181.1429	
6,00	13		337.9646
Sig.		0.467	1.000

As a result of the analysis, the effect of coolant pressure on tool wear is found to be very important ( $P < 0.01$ ). Duncan multiple comparison test is applied after variance analysis.

When the classification is made according to the Duncan test results, the lowest tool wear values are calculated as 142  $\mu\text{m}$  - 181  $\mu\text{m}$  as a result of cutting tests under 100 and 300 bar coolant pressure, and these values are included in the same classification. The tool wear at the cutting process under 6 bar coolant is calculated as 337  $\mu\text{m}$  which is almost 2 times of other tests. In the light of these data, no difference is observed in the tool wear during cutting of the Inconel 718 material under 100 or 300 bar pressure. After tests under three different pressure conditions, it is determined that the maximum tool wear is occurred at 6 bar coolant pressure.

## RESULTS

In the results of 32 cutting experiments under different coolant pressure; according to the analysis of variance between coolant pressure and vibration, it is observed that the minimum vibration is at 100 bar pressure. According to this result, it can be said that 6 bar coolant pressure does not cool the vibration at the cutting end sufficiently, and 300 bar coolant pressure creates additional vibration at the cutting end. When evaluated in terms of shear forces, it is seen that the pressure applied with the least force is 100 bar with the coolant pressure of 300 bar. It is observed that more force is applied in order to take place the cutting operation at 6 bar coolant pressure. When examined in terms of tool wear, it is observed that the minimum tool wear is during the coolant

pressure of 100 bar. Here it is observed that a similar result is produced by vibration. According to this result, it can be said that there is a direct relationship between vibration and tool wear. In the light of all these data, 100 bar pressure value is determined as the most ideal coolant pressure between 6, 100 and 300 bar coolant pressures during the processing of Inconel 718 super alloy material. Other cutting parameters (cutting speed, feed rate, cutting depth) are selected from the parameters accepted in the literature and kept constant.

## REFERENCES

- Alvarez, J.D., Tapetado, A., Vazquez, C., Miguelez, H. (2017). Temperature Measurement and Numerical Prediction in Machining Inconel 718. *Journal of Sensors*, 17, 1531.
- Bhuiyan, S.H., Choudhury, A. (2015). Investigation of Tool Wear and Surface Finish by Analyzing Vibration Signals in Turning Assab-705 Steel. *Machining Science and Technology*, 19(2): 236-261.
- Chuangwen, X., Jianming, D., Yuzhen, C., Huaiyuan, L., Zhicheng, S., Jing, S. (2018). The relationships between cutting parameters, tool wear, cutting force and vibration. *Advances in Mechanical Engineering*, 10(1): 1-14.
- Germer, H. (2001). High-Precision AC Measurements Using the Monte Carlo Method. *IEEE Transactions on Instrumentation and Measurement*, 50(2): 457-460.
- Güllü, A., Karabulut, Ş., Güldaş, A. (2008). Inconel 718 süper alaşımların işlenmesinde talaş kırılma problemleri ve talaş kırıcı tasarımı. *Gazi Üniversitesi Mühendislik Mimarlık Fakültesi Dergisi*, 23(1): 157-164.
- Güngör, O. (2011). Real Time Monitoring Cutting Tool Vibration, M.Sc.Thesis, Süleyman Demirel University Graduate School of Applied and Natural Sciences Electronic Computer Education Department, Isparta, Turkey.
- Hegab, H., Kishawy, H.A. (2018). Towards Sustainable Machining of Inconel 718 Using Nano-Fluid Minimum Quantity Lubrication. *Journal of Manufacturing and Materials Processing*, 2, 50.
- Kamruzzaman, M., Dhar, N.R. (2009). Effect of High Pressure Coolant on Temperature, Chip, Force, Tool Wear, Tool Life and Surface Roughness in Turning AISI 1060 Steel. *G.U. Journal of Science*, 22(4): 359-370.
- Kindi, Y.A., Murali, R.V., Salim, R.K. (2018). Tool Wear Investigation in CNC Turning Operation. *Proceedings of the World Congress on Engineering Vol II, July 4-6, London, U.K.*
- Lotfi, M., Amini, S., Aghaei, M. (2018). Tool Wear Prediction and Surface Improvement in Vibration Cutting, *Tribology Transactions*, 61(3): 414-423.
- Lohithaksha, M., Maiyar, L.M., Ramanujam, R., Venkatesan, K., Jerald, J. (2013). Optimization of Machining Parameters for End Milling of Inconel 718 Super Alloy Using Taguchi Based Grey Relational Analysis. *Procedia Engineering*, 64: 1276-1282.
- Ozel, T., Hsu, T-K., Zeren, E. (2005). Effects of cutting edge geometry, workpiece hardness, feed rate and cutting speed on surface roughness and forces in finish turning of hardened AISI H13 steel. *International Journal of Advanced Manufacturing Technology*, 25: 262-269.

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- Ozel, T., Zeren, E. (2007). Finite element modeling the influence of edge roundness on the stress and temperature fields induced by high-speed machining. *International Journal of Advanced Manufacturing Technology*, 35: 255-267.
- Paul, P.S., Varadarajan, A.S., Gnanadurai, R.R. (2016). Study on the influence of fluid application parameters on tool vibration and cutting performance during turning of hardened steel *Engineering Science and Technology*, 19: 241-253.
- Petrović, P.B. (2015). A New High Precision Power Detector of Complex Voltage Signals. *Measurement Science Review*, 15(4): 184-195.
- Prasad, B.S., Babu M.P. (2017). Correlation between vibration amplitude and tool wear in turning: Numerical and experimental analysis. *Engineering Science and Technology*, 20: 197-211.
- Ramakrishnana, R., Karunamoorthy, L. (2008). Modeling and multi-response optimization of Inconel 718 on machining of CNC WEDM process. *Journal of Materials Processing Technology*, 207: 343-349.
- Revankara, G.D., Shettyb, R., Raoc, S.S., Gaitonde, V.N. (2014). Analysis of Surface Roughness and Hardness in Titanium Alloy Machining with Polycrystalline Diamond Tool under Different Lubricating Modes. *Materials Research*, 17(4): 1010-1022.
- Salımaslı, A., Rafıghı, M. (2016). Titreşim ve Kesme Kuvveti Esaslı Takım Aşınmasının Bulanık Mantıkla İzlenmesi ve Tahmini. *Journal of Polytechnic*, 20(1): 111-120.
- Xavior, M.A., Manohar, M., Jeyapandiarajan, P., Madhukar, P.M. (2017). Tool Wear Assessment During Machining of Inconel 718. *Procedia Engineering*, 174: 1000-1008.
- Yan, P., Rong, Y., Wang, G. (2016). The effect of cutting fluids applied in metal cutting process. *Journal of Engineering Manufacture*, 230(1): 19-37.
- Yılmaz, V., Dilipak, H., Sarıkaya, M., Yılmaz, C.Y., Meral, G. (2014). Frezeleme İşlemlerinde Titreşimi ve Yüzey Pürüzlülüğünü Etkileyen Parametrelerin Optimizasyonu. *Suleyman Demirel University Journal of Technical Sciences*, 4(1): 37-44.
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