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Investigation of effects of inverter frequency changes on the specific energy consumption of pipe threading using response surface methodology

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ABSTRACT

In the manufacturing sector, energy requirements are increasing day by day. Consequently, energy production costs, which are directly affected by economic development, have risen as a result. Pipe threading operations are carried out on special pipe fitting threading machines. In there, threading is achieved with a low number of revolutions and high torque values. In this study, a novel threading machine was produced with an inverter system and inverter outputs controlled by current transformers and ammeters. The process power index (PI) was measured at 25–50 Hz frequencies. A new energy consumption model unlike any in the literature was created for this type of production line and the necessary calculations were made. Results were evaluated based on static response surface methodology (RSM) and experimental design. The effect of the diameter of the pipe contributed 84% and frequency changes 9%, whereas the effect of the product type was approximately 6%.

1. Introduction

Uncontrolled energy consumption has become a big problem these days. Due to limited resources, energy saving has been the main topic of very important research [1–3]. Contrary to common belief, energy saving does not mean only a lower amount of energy consumption. The literal meaning this word conveys is that the same amount of goods and services can be produced with a lower rate of energy or that more goods and services can be produced with the same amount of energy. Achievement of such an important goal increases the competitiveness of industrial enterprises in the national and international arenas. There is a worldwide need for energy in four different sectors: the industrial, transportation, residential and commercial (Fig. 1) [4]. The highest energy consumption is found in industry (51%). According to studies carried out on a sectoral basis, energy consumption in the metal industry is 10.7% [4]. These data findings indicate that energy saving has become unavoidable for the industry (Fig. 1).

The recent increase in energy demands and the insufficient amount supplied by new energy sources have led to a significant increase in world energy production costs in the last decades [5]. As a global concept, this covers important elements of many engineering fields and applications for sustainable production [6]. The adoption of sustainable production practices enables industrial enterprises to improve their economic and environmental performance. Investigating measures to be taken in order to achieve reduction of the energy consumption of machine tools and development of clean production is of great importance in the area of machining processes where a large amount of energy is consumed [7]. Sustainable production of fittings is very difficult due to the requirements of the manufacturing process, which include the high temperature needed for casting and the subsequent long-term heat treatment as well as threading and coating requirements, all of which generate high energy consumption [8]. The walls of pipe fittings are thin (5, 10, 15 and 20 mm), causing their cooling rates to be very high (1.66–2.85 °C/s) after the casting process, which is a major problem with these products [9]. Workability is reduced when microstructures of ferrite, pearlite and bainite are formed due to the rapid cooling rate. When austempering heat treatment is applied, fragility is reduced as hardness increases, and this treatment was reported by Öktem et al. to negatively affect processability [10].

Current threading operations are usually performed on manual threading machines. Fittings are produced via different methods, the most common being a threading process of 6–10 steps using a lathe with hard metal inserts [11,12]. Because of insufficienct machine power, threading operations performed by interpolation are applied in three or four operations on a computer numerical control (CNC) machine [13,14]. As an alternative threading process,

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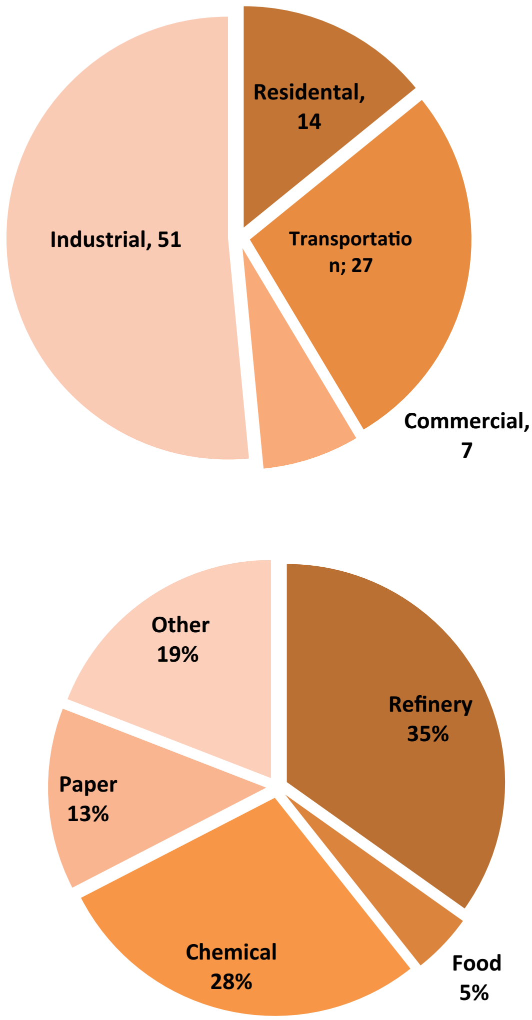

Fig. 1. World wide energy consumption (Up) and usage by sectors (Down).

the cycles with high torque and low speed are shortened and serial production is performed in one operation with special threading machines [15]. In the industry, pipe threading is carried out on specially developed tooling machines. These machines work with a pitch control system and produce a high amount of torque at low spindle speeds to carry out threading operations. The author has designed a three-head threading machine for this study (Fig. 2). This machine is made entirely of spheroidal cast iron to achieve ideal machining conditions under the high engineering stresses and vibrations that occur during the chip removal process. When the system is operating, the threading can be performed with three different spindles at 90° angles working simulaneously.

The process of manufacturing pipe fittings consumes a great amount of energy due to the high temperature required for casting and subsequent long-term heat treatment in addition to the requirements for threading and coating, thus making sustainable production very difficult [10]. The chief problem of these fittings is due to their thin walls (5, 10, 15 and 20 mm), which are responsible for very rapid cooling rates (1.66–2.85 °C/s) following casting. This leads to ferrite, pearlite and bainite microstructure formation (Fig. 2) which reduces the workability. In order to solve the machinability problem caused by these metallographic obstacles of cast-iron materials, an inverter automation system with four levels was mounted on the machine. Fig. 3 shows the circuit diagram of the automatic control unit of this improved machine. The technical specifications of the serial production machine with this automatic control are given in Table 1.

In this article, researchers have developed a threading machine with inverter and control unit. It is aimed to provide optimum energy consumption in pipe threading process which causes very high energy consumption in mass production. Thus, optimum machining conditions were determined by using RSM method. A new mathematical model is also proposed for pipe threading.

2. Energy consumption models during chip removal

One method in extensive use today for the evaluation of machinability is to determine the energy consumption of the chip removal. Using this method, the present study proposed to evaluate machinability by measuring the power consumed during threading using tap tools. In one study, the effect of cutting parameters on power consumption in the CNC milling of 6082 T6 aluminum alloy was investigated. As a result of this research, it was observed that energy consumption could be reduced by 82% by selecting optimum chip removal characteristics [16]. Industrial grade granite was cut using a saw and the power consumption measured [17], and the energy consumed in the milling of ASSAB 760 steel was determined using a power meter in another study [18]. The milling of 303 stainless steel was carried out under various conditions including dry cutting [19]. In the machining of Al 6061-T6 alloy on a CNC lathe, the power consumption throughout the process was determined and minimized [20]. In the high-speed ball-end milling of AISI H13 steel, the effects of process parameters on energy consumption were examined in one study [21], and another tested machinability using spheroidal graphite cast iron using In one study, an energy model was proposed for the entire cycle of the machining process on a CNC machine by using Equation (1) [22]. MRR stands for material removal rate and P stands for power.

$$\boldsymbol{SEC}\left(\frac{J}{mm^3}\right) = \frac{P\ total(W)}{MRR\left(\frac{mm^3}{s}\right)} \tag{1}$$

During the turning process, using different cooling techniques, ecological effects of new cutting fluids were investigated, and energy consumption was measured [23]. During the machining process, the power index (PI) measurement of the spindle servo motor drive was converted to kWh in this study using an ammeter by means of 3-phase motor power conversion, as shown in Eq. (2). In this equation I power index, V voltage and cos a is the motor efficiency value.

$$\boldsymbol{P\ total} = \sqrt{3}.V.I.Cos\ \sigma \tag{2}$$

In the machining of Al 7075 alloy, an end mill was used and the study presented a new power consumption model for optimum energy, surface roughness, and shear force values [24]. The authors used Eq. (3) when determining the specific energy consumption.

$$\boldsymbol{SCEC} = \frac{P\ cuttimg}{MRR} \tag{3}$$

Gutowski et al. proposed the first energy consumption model in this sub-category. The power consumed (**P**) in a unit process was broken down into an idle constant ($\mathbf{P}_{\text{idle}}$) and a variable proportional to the material removal rate, as expressed in Eq. (4) [25].

$$P = P_{\text{idle}} + k \cdot \text{MRR} \tag{4}$$

Here, k represents the coefficient related to the specific process, although this model is without experimental verification. Because no clear definition is given for each factor, its practical application is limited and thus cannot be used for a specific process on a particular machine tool. Li and Kara presented the first energy consumption prediction model for practical use [26]. They used an empirical method to find the inverse relationship between the

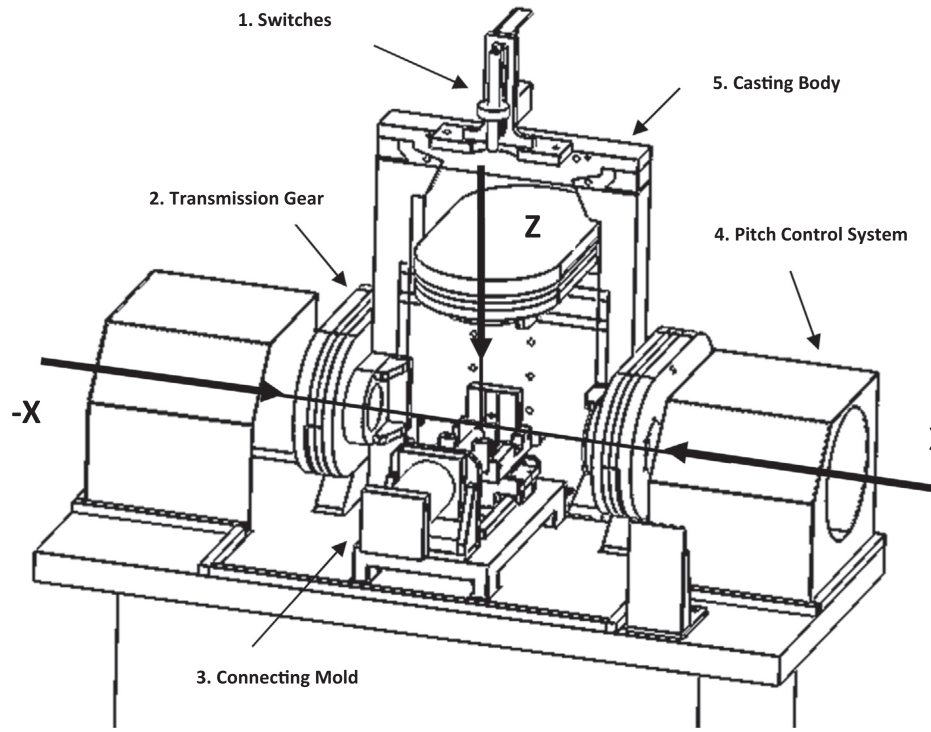

Fig. 2. Three-head threading machine designed by author.

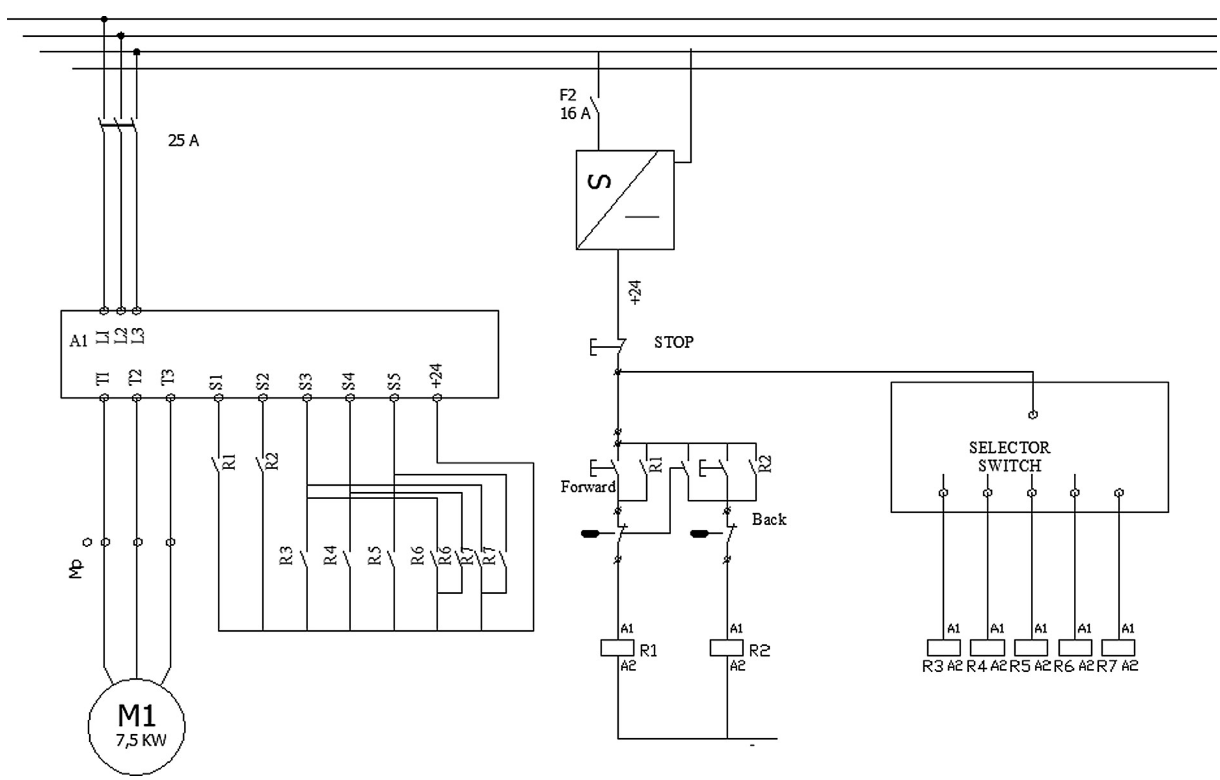

Fig. 3. Inverter automation system.

Table 1
Serial production machine technical specifications.

Power (kW)	Pipe Diameter (inc)	Voltage (V)	Frequency (Hz)
7.5	¾–1	380	25, 30, 40, 50

specific energy consumption (*SEC*) and *MRR* for a CNC workbench, as given in Eq. (5). Investigations have been conducted on the correlations between spindle rotation speed (rpm), cutting parameters, *MRR*, *SEC*, cutting power, and material removal power [27].

$$\mathrm{SEC} = C_0 + \frac{C_1}{MRR} \tag{5}$$

Energy and power consumption during machining are expressed in the literature with these five different equations. In one study, an energy model was proposed for the entire cycle of the machining process on a CNC machine [28]. This equation is the broadest definition of energy consumption in mass production machining. The spindle is considered as the principal part of a machine tool. The spindle unit power model based on the energy current of the mechanical and electrical systems was established using Eq. (6) [29,30]. The spindle power ($\mathbf{E}_s$) consists of no-load power ($\mathbf{P}_u$), cutting power (P_c) and the additional load loss power ($\mathbf{P}_a$). It is important to note that additional energy loss is not a constant and that it is dependent upon the spindle power. Aprediction model for spindle unit energy consumption was subsequently developed.

$$E_s = P_u \cdot t_M \int_0^{t_M} P_a(t)dt + \int_0^{t_M} P_c(t)dt \tag{6}$$

Response Surface Method is a method used in many scientific researches to determine optimum conditions [31–35]. The RSM was developed by Box and Wilson in 1951 [31,32] and is defined as a method using both statistical and mathematical techniques for developing and optimizing processes. This method can determine the correlation between experimental approaches, the system response and the independent variables affecting it. Included in the method also are empirical modeling and optimization techniques used to find the levels at which the desired effect is shown by the process variables in the system response [32]. To investigate the relationship between independent and dependent variables, multiple regression methodologies involving least squares are generally applied [33,34]. Multiple regression equations can be used to fit the second order polynomial equation based on experimental data via Eq. (7) where y represents the predicted response, β_0 is the model intercept, and β_i, β_{ii} ,and β_{ij} are the regression coefficients for the linear, quadratic, and interactive effects of the model, respectively. X_i and X_j are the factors and k is the number of factors [35].

$$y = \beta_0 + \sum_{i=1}^{k} \beta_i X_i + \sum_{i=1}^{k} \beta_{ii} X_i^2 + \sum_{i \neq j=1}^{k} \beta_{ii} X_i X_j + \varepsilon \tag{7}$$

3. Material and methods

In industry, 1- and ¾-inch sized pipe fittings are used at a high rate in installation systems. Therefore, this study investigated energy consumption values for Tee and elbow fittings, which are produced in the sector in these widely used sizes. The asynchronous motor was driven using an inverter at frequencies of 25, 30, 40 and 50 Hz. In order to examine energy consumption, a threading machine with an automatic control unit has been developed. Then, according to the experimental design, threading was performed. Changes in spesific energy consumption were calculated with the proposed a new model. Optimum energy consumption conditions were determined by RSM method too (Fig. 4).

This study discusses the use of the response surface methodology (RSM) experimental design in the threading process for these products of different types and dimensions and at different asynchronous motor operating frequencies. Table 2 shows the design of experiments (DOE) for the RSM implementation.

In this study, the energy consumption of two different sizes and product types shown at different frequencies was evaluated using RSM. Thus, for the first time in the literature, RSM has been used for the characterization of the machinability performance of a fitting produced via serial production for industrial application. For this study, the design of the reduction product was produced in accordance with TS 11 - EN 10242 standards. Using the Oxford Foundry Master Pro spectrometer a chemical analysis was carried out on the materials used in the experimental study (after casting) and the results are shown in Table 3.

Three replicates were performed for each experiment by dividing the materials into groups. The pipe threading was carried out on the threading machine using a Wellcut tap tool having a diameter of 17.5 mm and 40 mm in length (L/D < 3) (Fig. 5). The reduction materials were attached to the threading machine workbench and the chuck assembly was used in order to carry out the threading operation.

In this developed manual threading machine, power indices (PI) were measured using a current transformer and an ammeter during the pipe threading process. As a result, the power index changes are shown in the graph in Fig. 6. In this graph, it can be seen that power index and power changes occurred in three different regions.

The power index values in the first region are measured during the first time period. The start button is pressed by the operator and the guide begins to approach the workpiece. This time period can be expressed as "approach time" and in this region, the guide advances with the engine speed determined by the inverter ($\boldsymbol{P}_{AAT}$). In the second time period, the threading process takes place and at this time the machine is idle ($\boldsymbol{P}_{Threading}$) and the current used to perform the threading process ($\boldsymbol{P}_{ATT}$) is measured together with it ($\boldsymbol{P}_{Total}$). The final period encompasses the separation of the product via the effect of friction under the return speed when the threading process is completed. The current changes are then measured during the progression to the switch and stopping of the motor ($\boldsymbol{P}_{ART}$). This time period can also be classified as "retract time". During this period, using the inverter to save time, a frequency of 100 Hz is provided and the guide moves to return with the maximum speed. The average of the energy consumption in these three regions determines the actual energy consumption ($\boldsymbol{P}_{Real}$). The equations used in the calculations of these energy consumption results are given below as Eqs. (8–10).

$$P_{Total} = \sum_{j=1}^{Q_{ATT}} P_{ATTj} \tag{8}$$

$$P_{Threading} = \sum_{j=1}^{Q_{ATT}} P_{ATTj} - \sum_{i=1}^{Q_{AAT}} P_{AATi} \tag{9}$$

$$\boldsymbol{P}_{Real} = \boldsymbol{P}_{AAT} + \boldsymbol{P}_{ATT} + \boldsymbol{P}_{ART} \sum_{i=1}^{Q_{AAT}} P_{AATi} + \sum_{j=1}^{Q_{ATT}} P_{ATTj} + \sum_{k=1}^{Q_{ART}} P_{ARTk} \tag{10}$$

The types of energy consumption in chip removal operations are defined as: the (total) specific energy consumption (*SEC*) and the specific cutting energy consumption (*SCEC*) required to remove 1 mm^3 of chip, as shown in Eqs. (11) and (12). MRR in these equations is the amount of chip removed during unit time change.

$$\boldsymbol{SEC} = \frac{\sum_{j=1}^{Q_{ATT}} P_{ATTj}}{MRR} \tag{11}$$

$$\boldsymbol{SCEC} = \frac{\sum_{j=1}^{Q_{ATT}} P_{ATTj} - \sum_{i=1}^{Q_{AAT}} P_{AATi}}{MRR} \tag{12}$$

The *SCEC* is directly associated with the workability of the material. The *SEC* is a parameter defined in removal of the chip during machining and in rotating the motor. Industrial electricity costs are directly related to the $\boldsymbol{P}_{Real}$ parameter. This is because the

Fig. 4. Research process diagram.

Table 2
RSM experimental design.

DOE	Pipe Diameter (inch)	Product Type	Frequency	Std Order	Run Order	Blocks	Pt Type
1	1	Tee	25	1	1	1	1
2	1	Elbow	30	2	2	1	1
3	1	Tee	40	3	3	1	1
4	1	Elbow	50	4	4	1	1
5	1	Tee	25	5	5	1	1
6	1	Elbow	30	6	6	1	1
7	1	Tee	40	7	7	1	1
8	1	Elbow	50	8	8	1	1
9	3/4	Tee	25	9	9	1	1
10	3/4	Elbow	30	10	10	1	1
11	3/4	Tee	40	11	11	1	1
12	3/4	Elbow	50	12	12	1	1
13	3/4	Tee	25	13	13	1	1
14	3/4	Elbow	30	14	14	1	1
15	3/4	Tee	40	15	15	1	1
16	3/4	Elbow	50	16	16	1	1

Table 3
Chemical analysis of fitting materials.

Element	Fe	C	Si	Mn	P	S
After spheroidal (%)	93.3	3.58	2.64	0.14	0.03	0.015

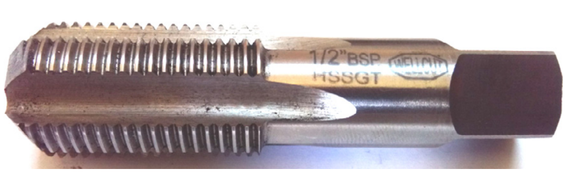

Fig. 5. Wellcut ½ inch BSP tap tool.

energy consumption averages of the cutting tool when approaching and retracting from the workpiece are collected along with the average energy consumed during the threading. The ratio of this consumption to the total volume of chip removed reveals the value of SEC_{Real} by using Eq. (13). In this study, the results were obtained by using these equations in the calculation of special energy consumption types.

$$\boldsymbol{SEC_{Real}} = \frac{\sum_{i=1}^{Q_{AAT}} P_{AATi} + \sum_{j=1}^{Q_{ATT}} P_{ATTj} + \sum_{k=1}^{Q_{ART}} P_{ARTk}}{MRR} \quad (13)$$

4. Results and discussion

The pipe threading process was carried out with the experimental design parameters and levels determined for the manual threading machine produced as a prototype. During this threading process, energy consumption was measured by means of an ammeter. Amperage changes were recorded for each time interval. The graphs in Figs. 7 and 8 show power index changes at different frequency ranges during threading operations for a 1-inch elbow and a 1-inch Tee fitting, respectively. When these graphs are examined, the average values of power index changes measured for different frequencies can be seen. The values of these power indices varied in the three different regions. In particular, it was observed that the output frequency of 100 Hz and the retract time when the guide was moving back from the workpiece showed lower values of energy consumption than the approach time. The asynchronous motor was activated when the start button was pressed and when the stop switch was actived after the motor return, an instantaneous power index increase was observed in the motor current.

Table 4 shows power index measurements. It was observed that the approach and retract power indices for the Tee and elbow fittings were approximately the same. It was determined that the increase in the power index between the threading of the elbow fitting and the Tee fitting of the same size was 53%. The most likely cause of this was that for the elbow type, a 2-axis threading process was performed, while for the Tee type a 3-axis production was carried out.

The power indices measured using Eqs. (8–13) were converted into energy consumption results (Table 5). When these results were examined, it was determined that the value of *SEC* decreased as the product size increased. Although the increase in this $\boldsymbol{P}_{Total}$

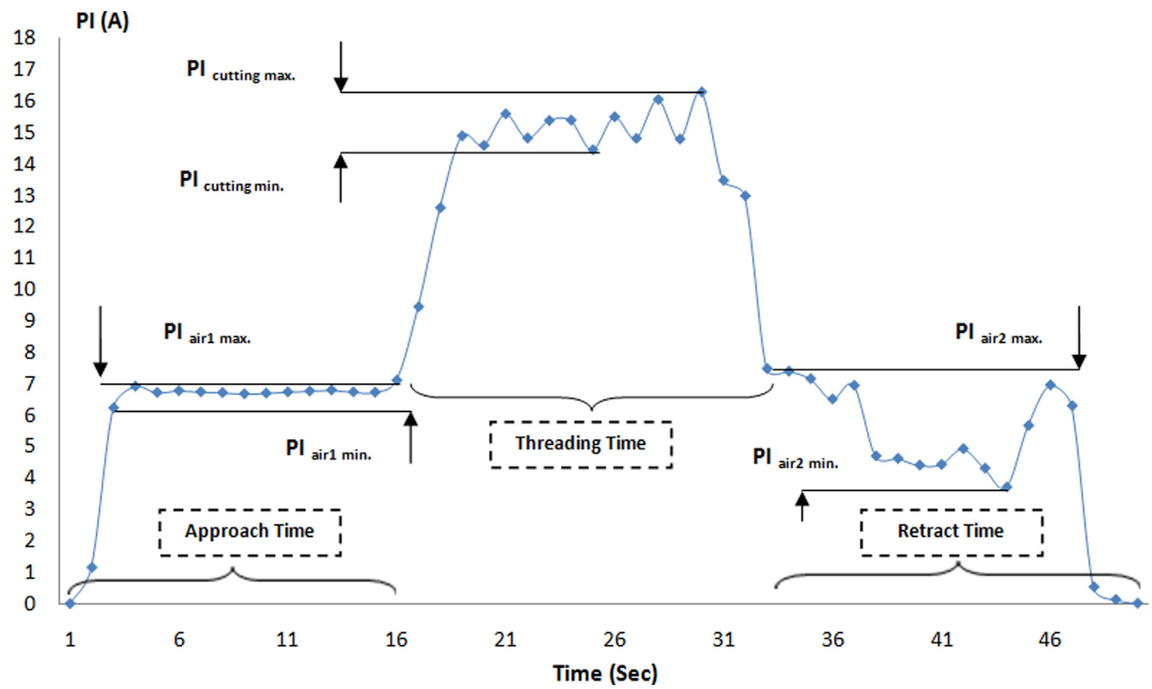

Fig. 6. Power index changes.

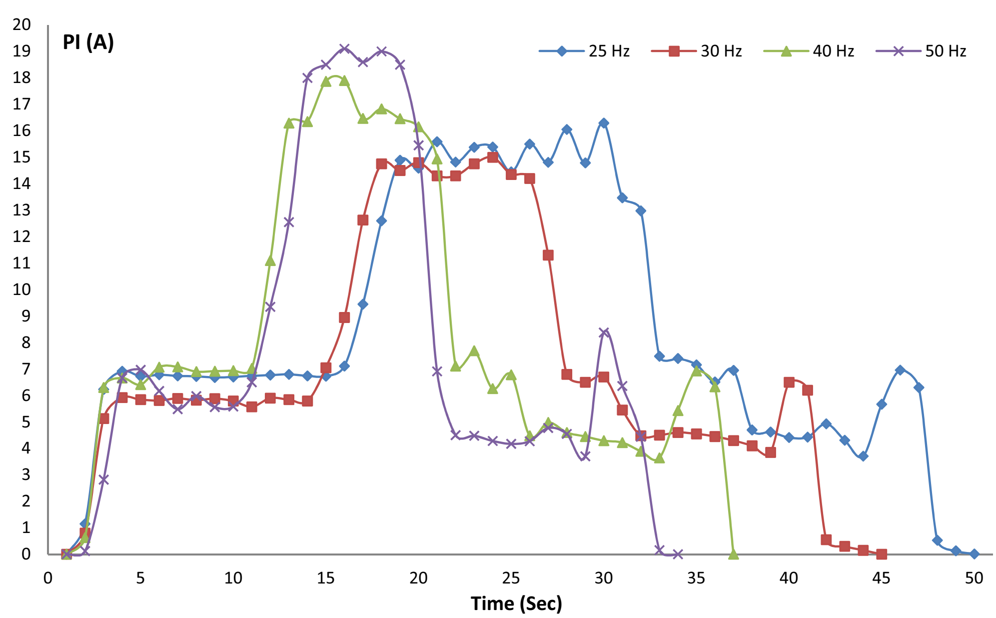

Fig. 7. Power index changes depending on frequency for 1-inch elbow fitting.

value was not the same, the increase in *MRR* revealed this result. The parameter that determines the energy consumption expenses in industry is the SEC_{Real} value and the optimum SEC_{Real} value in the pipe fittings was obtained at a frequency of 50 Hz. The *SCEC* is the value that varies in parallel with the machinability and cutting forces of the materials. The lowest *SCEC* values were 40 Hz for the elbow fitting and 50 Hz for the Tee fitting.

Surface plot graphs obtained using Minitab software RSM tools showing the relationship between frequency changes and the power indices and pipe diameter are given in Fig. 9. When these results are considered, the change in pipe diameter was was affected in direct proportion to the $\boldsymbol{PI}_{Total}$ value by a high rate of frequency change. The effect of these frequency changes on $\boldsymbol{PI}_{Threading}$ values was greater than on the pipe diameter. However, the effect of frequency was slightly lower after 35 Hz. it was determined that a high rate of frequency change had more effect on the $\boldsymbol{PI}_{Approach}$ parameter than on the pipe diameter change. When the $\boldsymbol{PI}_{Real}$ changes are examined. It can be seen that the ideal frequency value would be between 35 and 40 Hz; however, the pipe diameter change had a direct effect on the result.

The relation between pipe diameter and frequency changes in the *SEC*, *SCEC* and *MRR* results is shown by the surface plots in Fig. 10. According to these results. It can be said that the ideal frequency range for processing would generally be 30–40 Hz. A very high rate for pipe diameter change was observed in all values. According to these results, the energy consumption costs of the fittings materials increased as the diameter size decreased.

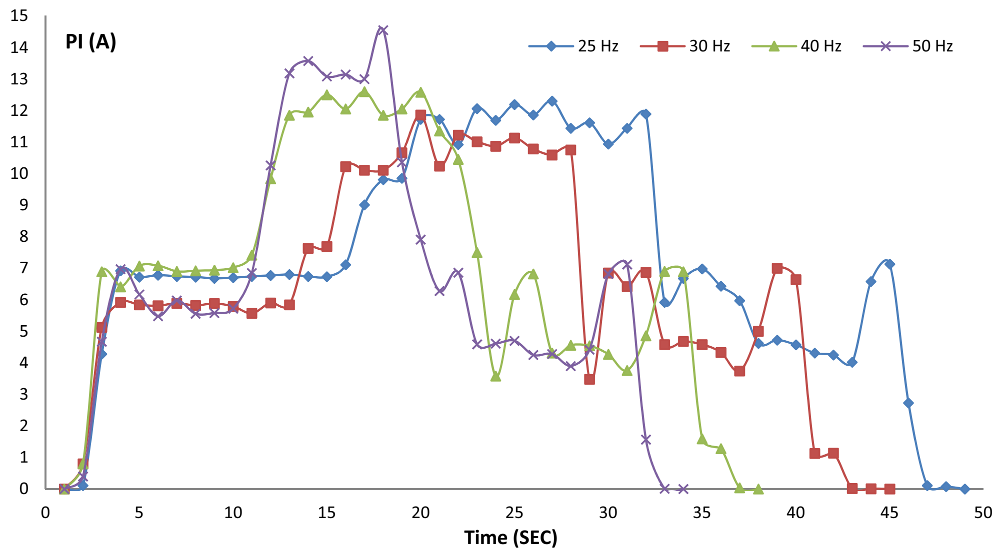

Fig. 8. Power index changes depending on frequency for 1-inch Tee fitting.

Table 4
Power index measurements.

Number of DOE	$PI_{Approach}$ (A)	PI_{Total} (A)	$PI_{Retract}$ (A)	$PI_{Threading}$ (A)	PI_{Real} (A)
1	5.97	15.08	4.75	9.11	8.60
2	5.97	11.43	4.69	5.46	7.36
3	5.14	14.55	4.61	9.41	8.10
4	5.30	10.73	4.84	5.43	6.96
5	5.63	16.58	4.88	10.95	9.03
6	5.45	11.73	4.75	6.28	7.31
7	4.71	18.16	4.68	13.45	9.18
8	4.80	12.98	4.81	8.18	7.53
9	6.07	14.35	4.80	8.28	8.41
10	6.12	9.85	4.62	3.73	6.86
11	5.44	13.85	4.75	8.41	8.01
12	5.35	9.35	4.78	4.00	6.49
13	5.78	16.13	4.85	10.35	8.92
14	5.64	10.46	4.75	4.82	6.95
15	5.39	16.73	4.70	11.34	8.94
16	5.27	11.53	4.89	6.26	7.23

Table 5
Energy consumption results.

Number of DOE	P_{Total}	*MRR*	*SEC*	*SCEC*	P_{Real}	SEC_{Real}
1	2.78	523.93	8.77	5.30	2.62	5.00
2	1.66	349.29	9.98	4.77	2.24	6.43
3	2.87	628.94	7.05	4.56	2.47	3.93
4	1.66	419.29	7.80	3.95	2.12	5.06
5	3.34	838.29	6.03	3.98	2.75	3.28
6	1.91	558.86	6.40	3.43	2.23	3.99
7	4.10	1047.86	5.28	3.91	2.80	2.67
8	2.49	698.57	5.66	3.57	2.30	3.29
9	2.52	209.36	20.89	12.06	2.56	12.24
10	1.14	139.57	21.51	8.15	2.09	14.99
11	2.56	251.16	16.81	10.21	2.44	9.73
12	1.22	167.44	17.02	7.28	1.98	11.82
13	3.16	334.97	14.68	9.42	2.72	8.12
14	1.47	223.31	14.28	6.58	2.12	9.49
15	3.46	418.71	12.18	8.26	2.73	6.51
16	1.91	279.14	12.59	6.84	2.20	7.90

The effects of the inverter frequency and pipe diameter changes of the products on the energy consumption results were investigated via the surface plot results. On the graphs, energy consumption results were obtained within the intermediate values of the experimental design parameter levels using this feature of RSM. The probability plots measured the accuracy of all the results of RSM. As the points became closer to the curve, the accuracy of the results was shown to be greater (Fig. 11). When this graph was examined, it was determined that the accuracy of the results was within the range of the desired values.

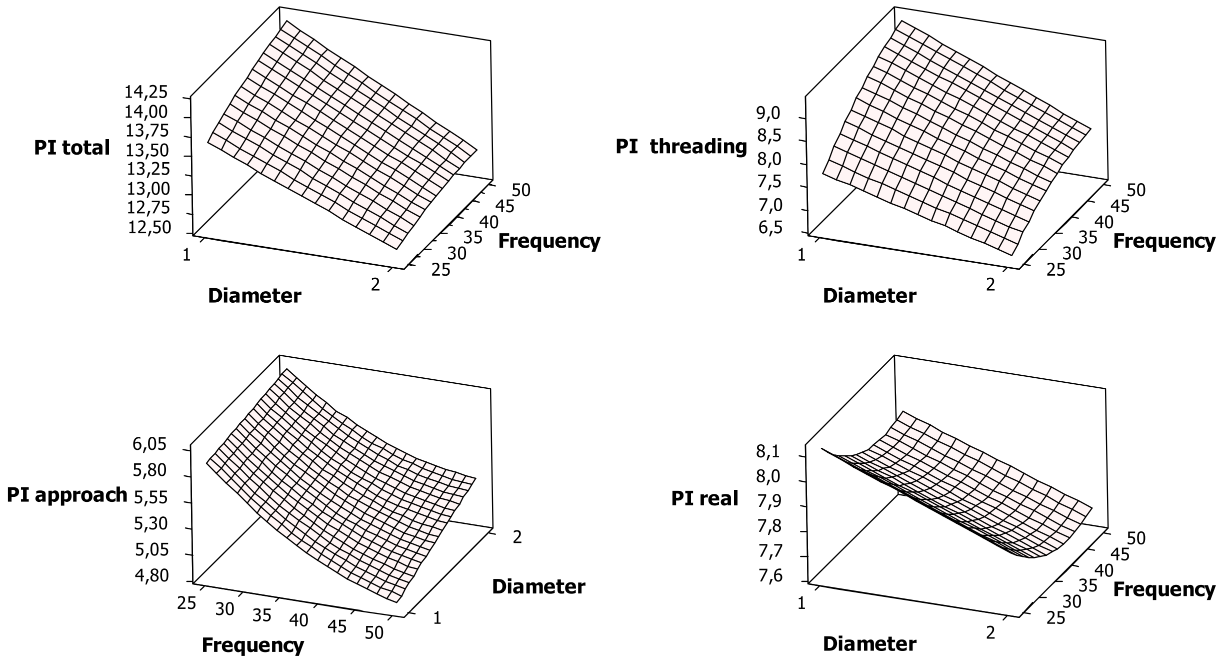

Fig. 9. Effect of frequency changes on power indices and pipe diameter.

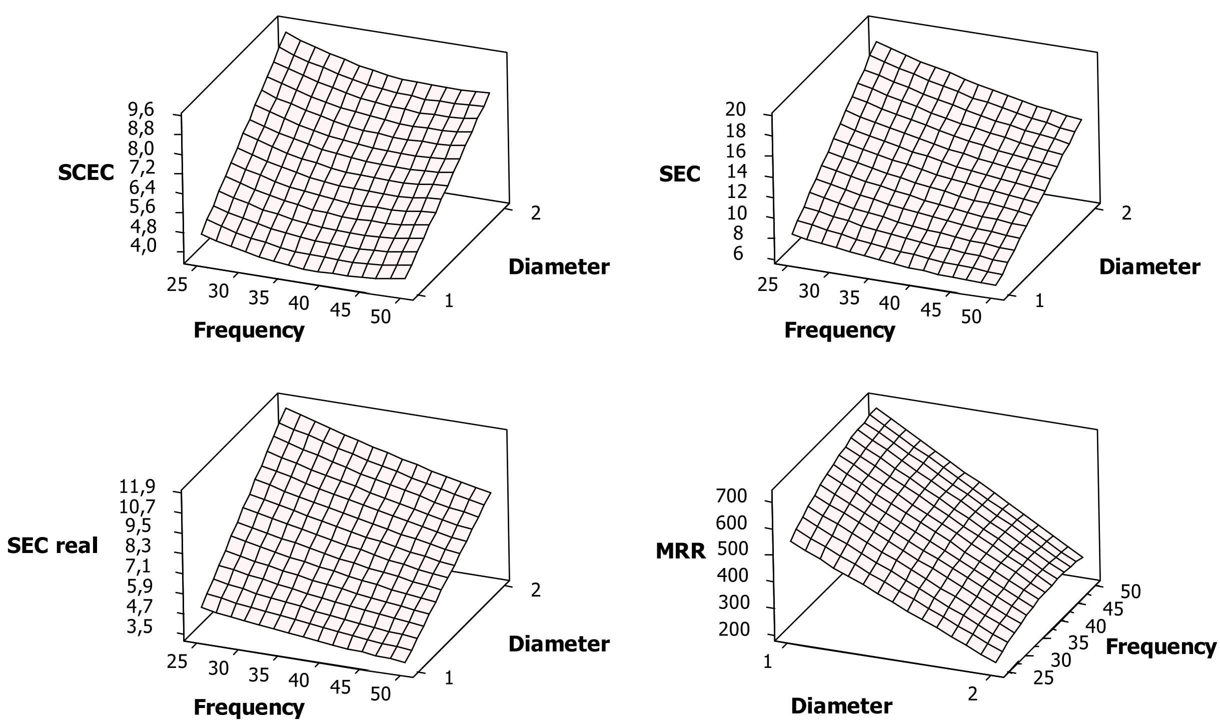

Fig. 10. SEC, *SCEC* and *MRR* results for pipe diameter and frequency changes.

The effect intensity of experimental design parameters on desired results can be determined by analysis of variance (ANOVA) [20,22]. The intensity of the frequency change of the $\boldsymbol{P}_{Real}$ value was defined as too high. For the *SEC* value, the decisive factor was the pipe diameter and then the product type. The SEC_{Real} was the most important parameter in the determination of the electricity consumption costs for the industry, with 84% of this as the diameter of the pipe and 9% the frequency changes, while the effect of the product type was approximately 6% (Table 6). The results of these analyses showed results in parallel with the surface plot results.

The model recommended in this article; the pipe takes into account the energy consumed by the guide in the air (P_{air}) and the time elapsed during these movements too. With this proposed new model, the SEC amount in the pipe threading process is calculated as 14.99 and in the general model it is determined as 21.51. This model provides the most accurate consumption result according to equality 1–5. Also, during this manufacturing process, the

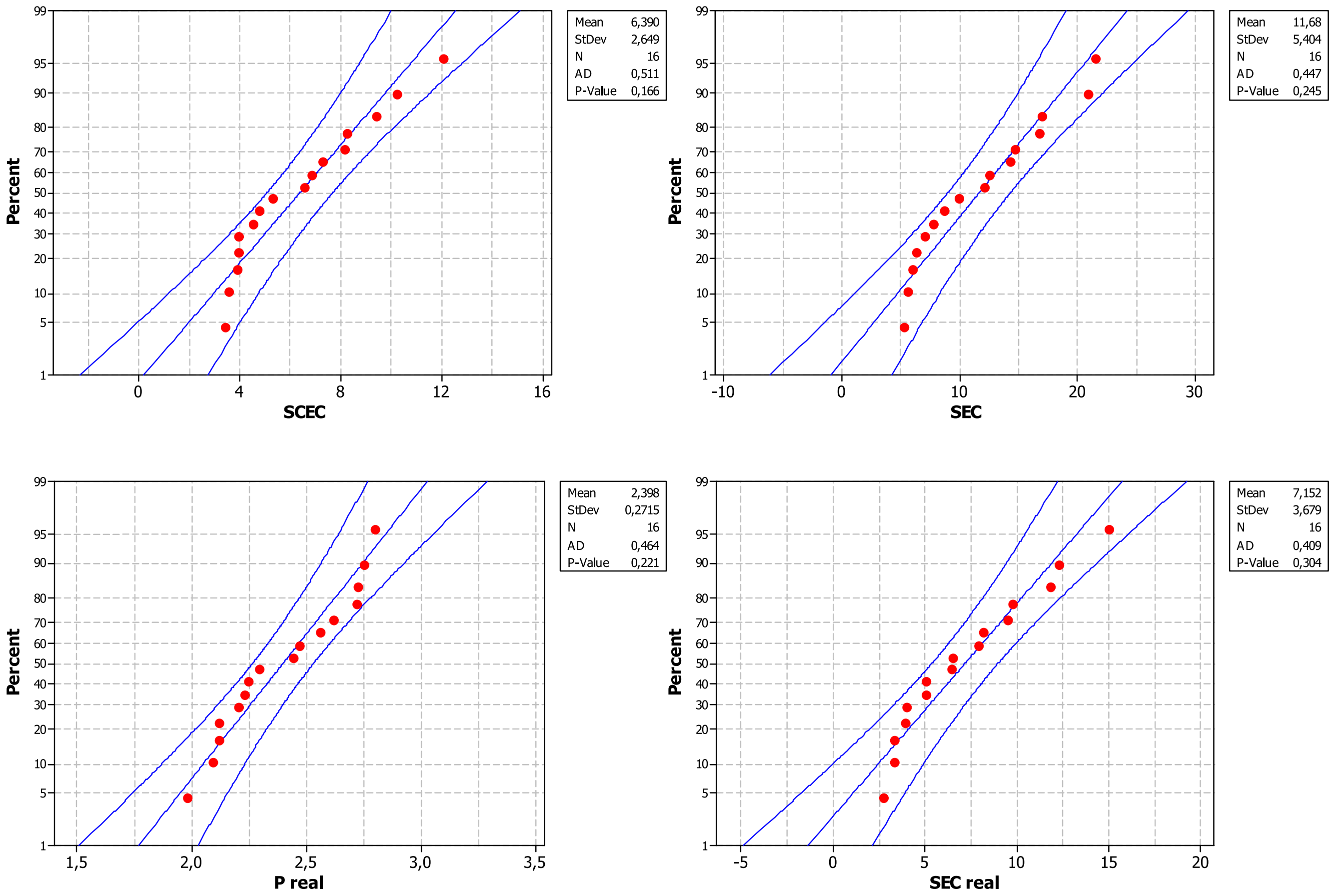

Fig. 11. Probability plots of RSM results.

Table 6
Analysis of variance (ANOVA) results.

Source	P_{Real}				SEC_{Real}				SEC			
	DF	Seq SS	F	P	DF	Seq SS	F	P	DF	Seq SS	F	P
Regression	6	0.94918	9.11	0.002	6	159.696	5.53	0.012	6	357.771	6.69	0.006
Linear	3	0.9415	17.74	0	3	157.158	10.35	0.003	3	353.924	12.62	0.001
Pipe diameter	1	0.02958	1.65	0.231	1	138.912	27.42	0.001	1	332.979	35.59	0
Hz	1	0.90696	40.73	0	1	8.228	2.94	0.121	1	0.784	0.64	0.444
Product Type	1	0.00496	0.27	0.619	1	10.017	2.06	0.185	1	20.161	2.22	0.171

output speed of the tap tool is determined by defining the motor frequency 100 Hz. This is one of the reasons for the decrease in private energy consumption. The researchers think that the energy savings in the manufacturing process can be realized with the help of artificial intelligence that will be added to the automatic control units in the future. This article is thought to be a reference source for special production machines with automatic control units.

5. Conclusions

Today, with the rise in energy consumption in the industrial sector, along with the shrinking resources and rising costs of electricity, research needs to be carried out in order to optimize the efficient use of energy in serial production enterprises. This study aimed to measure the power indices of serial-production pipe-threading processes under industrial conditions. Different inverter frequencies were compared in terms of machinability and product type and diameter comparisons were conducted via energy-power conversion equations. In this study, the DOE parameter levels for the optimum energy consumption value were obtained using RSM. As with studies reported in the literature, high reliability was observed, especially in the predicted results using the surface plot and probability plot tools [31,32].This was the first study using RSM for energy consumption optimization in a serial production application.

In the machining of 304 stainless steel, a maximum of 1.8 kWh was observed by Escalona et al. [19] Negrete examined three different techniques in the turning of 6061 aluminum and observed the maximum power consumption of 5.8 kWh in hole drilling [20]. In addition, in their study on the threading processes of cast and austempered fitting materials, Öktem et al. found that the threading of cast-iron fittings required a total power consumption of 16.5 kWh [10]. With the special threading machine connected to this developed inverter, it was observed that a current power consumption in the range of 4.10–1.14 kWh could be realized. With the use of these special production machines, threading could be performed on fitting products at high torque and low speed with optimum energy consumption. Energy savings of up to 47% were achieved on energy consumption for the highest materials. In this study, energy savings of 657 kWh could be obtained during annual serial production by selecting the optimum frequency.

Upon examination of the SEC_{Real} values of the 1-inch pipe fittings, energy consumption of 3.29 J/mm^3 was found, while this value was 2.67 J/mm^3 for elbow fittings at the same speed. It has been reported that companies stop production for high-cost components, especially small-diameter fittings involving high production costs. In concurrence with the findings of this report, the increase in energy consumption in this study was observed to be more than 100%. By applying the optimum conditions, the study found that this loss can be minimized in serial production by saving energy.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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