

# The Investigation of Marble Cutting Parameters for Energy Consumption

Hasan Çimen, Said Mahmut Çinar, and Mustafa Nartkaya

**Abstract**— Marble cutting process has very complexity structure with lots of machining and stone parameters. In this paper, a marble test machine fully controlled by PC is presented. The PC based marble test machine is designed for experimental tasks such as determining suitable cutting parameters, developing saw blade performance and marble cutting with optimum electric energy. PC based systems have lots of advantages such as rapid, functional, low cost, adaptable, attractive. PC based systems can also be used industrial environments for improving productivity. Presented PC based marble test machine whereby an experimental test machine was carried out to obtain precise results.

**Keywords**—PC based control, instrumentation, data acquisition, block-cutter, marble industry, cutting energy.

## I. INTRODUCTION

MARBLE which is important raw material worldwide is used in firstly building trade, indoor and outdoor decoration, ceramics, paper and paint industries [1-3]. There are important marble reserves in Turkey and large amount marble is exported. Marble industry is considerable in Afyonkarahisar region in the west of Turkey with stone quarries and lots of marble factory.

Block marbles removed from stone quarry are generally stripped by block-cutter with circular diamond segmented saw blade. The block-cutter is known as Stripper Trimmer (ST) in industrial applications. Marble sawing process has very complexity structure with lots of machining and stone parameters [1-2]. Therefore, determining of suitable parameters for each stone is major importance in marble industry and these parameters must be controlled during cutting process [3]. Many studies have been performed to understand sawing process structure and to improve sawing performance [4-7].

PC based systems are widely used in experimental devices designed for researches [8-11]. Also, lots of manufacturers

have extensively used PC based instrumentation systems for improving productivity and reducing costs [12].

The block-cutter presented in this paper is a prototype of ST machine and is fully controlled with personal computer (PC) so that precise and reliable experimental results can be obtained in short time. By means of interface software, all actions of machine are observed, controlled and actuated. In addition, experimental results can be saved to hard drive [20-21].

## II. REQUIREMENTS FOR EXPERIMENTAL SET-UP

PC based block-cutter is established upon requirements of users focused determining cutting parameters (Mining Engineering), developing cutter performance (Mechanical Engineering) and marble cutting with optimum electric energy (Electrical Engineering). Because of multi discipliner studies, there are lots of user requirements.

### A. Common requirements

- All actions of machine must be controlled via interface software.
- The machine should be controlled on automatic or manual mode and ten cutting experiments should be sequentially performed in automatic mode.
- Process status and errors must be showed.
- Saw blade rotation speed, work piece travel speed, cutting depth, flow rate of cooling water and cutting forces must be observed as real time.
- Stone information should be written to a data field.
- Cutting parameters should be written and constant parameters should be selected.
- Saw blade rotation speed must be changed from 0 to 4000rpm (0.1rpm resolution) and work piece travel speed must be changed from 0 to 4m/min (0.1m/min. resolution).
- Position of saw blade platform should be adjusted with 1mm resolution.
- Flow rate of cooling water should be adjusted from 0 to 20l/min (0.1l/min resolution).

### B. Electrical engineering requirements

- Consumed electric energy and demanded active power should be measured by energy analyzer and these values should be showed on screen.
- Line currents, active and reactive power and harmonic distortion on currents, voltages and powers should be

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recorded.

### C. Mining engineering requirements

- Cutting noise and saw blade diamond's temperature should be observed on screen.
- Cutting forces, cutting noise, saw blade diamond's temperature should be recorded.

### Mechanical engineering requirements

- Saw blade vibration speed and saw blade diamond's temperature should be displayed on interface software.
- Saw blade vibration speed and saw blade diamond's temperature should be recorded.

## III. EXPERIMENTAL SET-UP

### A. Hardware of Set-Up

Although the ST machines have vertical and horizontal saw blade, the block-cutter has only vertical saw blade. Horizontal saw blade is ineffective in cutting process. Therefore, only a vertical saw blade was used in block-cutter. The vertical saw blade moves in vertical and horizontal axis. Cutting process is provided with forward and backward movement of work-piece. Fig. 1 shows the block-cutter's mechanical architecture.

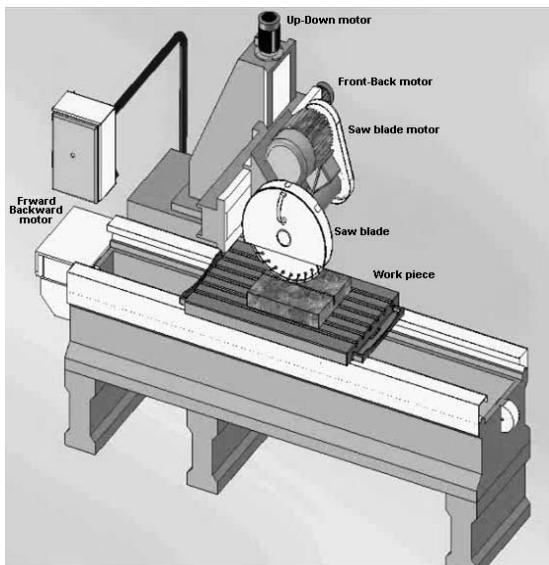


Fig. 1. Block-cutter's mechanic architecture

Cutting depth and slice thickness are adjusted to horizontal and vertical movement of saw blade platform. Saw blade platform's two axis linear movements are performed by sledge bearing and infinite gear systems. Work piece's linear movement is executed by wheel-chain system. Also saw blade's circular movement is performed by wheel-belt system (Fig. 1). Moreover, speed of saw blade positioning motors and work piece travel motor are geared down by reducer.

Induction motors are used in saw blade positioning (0,75kW), work piece movement (0,75kW) and saw blade rotation (7,5kW). Saw blade and work piece's induction motors are driven by inverter (Fig. 2). Saw blade rotation and work piece travel speeds by means of inverters are changed in

wide range (0-4000rpm and 0-4m/min). In addition saw blade's vertical and horizontal position is adjusted in high precise (in 1mm resolution).

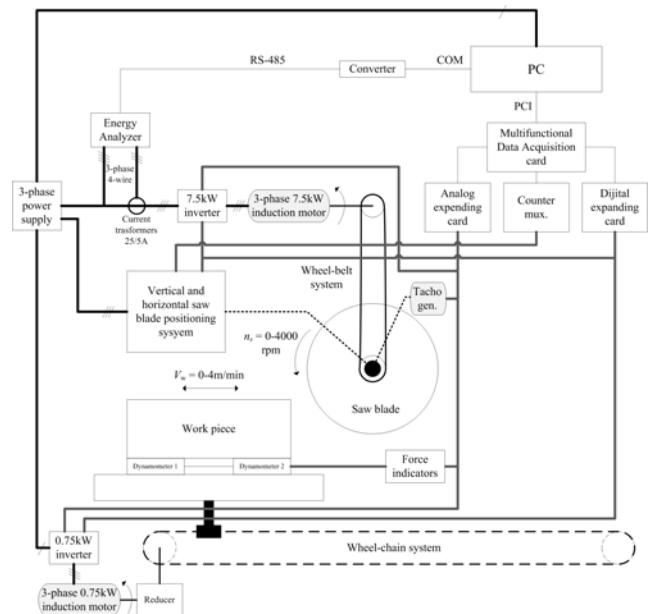


Fig. 2. Block scheme of DAQ system

Block-cutter's electrical system composes of induction motors' AC power supply, computer, sensors and indicators' DC power supply and energy analyzer's wiring systems and they locate in electrical panel (Fig. 3). Electric system of block-cutter is equipped with phase failure, phase sequence and over load protection systems [20]. Induction motors and all other devices are prevented by these protection systems.

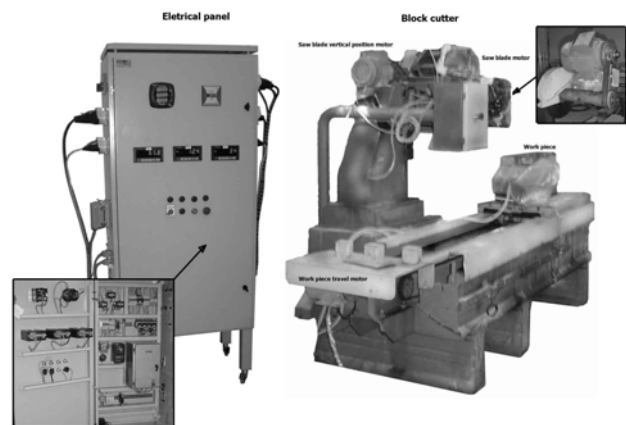


Fig. 3. Block-cutter and electrical panel

Data acquisition system is made of two main units. These are industrial and multifunctional data acquisition card and energy analyzer. The heart of instrumentation system is 16-bit 250kS/s multifunctional data acquisition card.

Data acquisition card has 16-bit 16-channel single ended or 8-channel differential analog input, 16-bit 2-channel analog output, 16-channel digital input, 16-channel digital output and 16-bit 1MHz programmable counter/timer. The card is

plugged into PC's PCI slot. Moreover, peripheral instrumentation devices (such as sensors, load cells, contactors, inverters, etc...) are connected with expanding cards (wiring terminal board, isolated digital input card, digital output card and counter multiplexer). PC and expanding cards locates in control panel (Fig. 4).

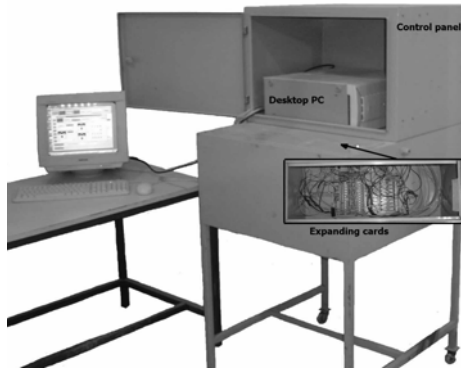


Fig. 4. Control panel and expanding cards

Saw blade motor's electrical parameters (phase and line current, phase and line voltages, active, reactive and apparent powers, active and reactive energy etc...) are measured with energy analyzer (Shark 100 made by Electro Industries/GaugeTech). The energy analyzer has 3 line LED display, RS-485 (for MODBUS communication) and IrDA (for PDA remote read) ports and 0.2% accuracy. In addition, harmonic and power qualify analyzing can be performed by the energy analyzer. Measuring connection of analyzer is wired with three-phase and four-wire (Fig. 2).

In addition data transfer is performed from energy analyzer to PC or from PC to energy analyzer by RS-485 communication ports. The converter (RS-485/RS-232) is used between PC and energy analyzer.

Cutting forces are measured by three axis dynamometer and force indicators. The dynamometer has three load cells which in 100N measuring capacity. Indicators produce analog voltage ( $\pm 10V$ ) according to load cell stress. When indicator's analog output reaches to  $+10V$ , the load cell stress is  $+100N$ .

### B. Software of Set-Up

Interface software is carried out with Delphi programming language (Fig. 5). The Delphi has the object oriented programming and is powerful in the integration of hardware and software. All of measurement, actuating, recording and analyzing tasks are performed with interface software.

By means of interface software, block cutter is controlled in manual or automatic modes. Sequential ten cutting experiments can be made in automatic mode. Also, the saw blade rotation speed, work piece travel speed and direction, saw blade position and flow rate of cooling water are adjusted in manual mode.

Interface software composes of four windows. These are "Marble Test Program", "Manuel Control", "Data" and "Serial Communication Setup" windows.

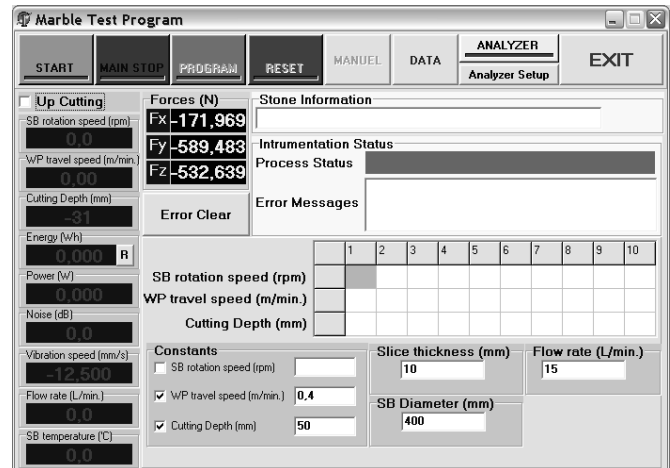


Fig. 5. The Interface software main window

Lots of information can be seen on the main window, such as displays, buttons, data fields, etc... The main window composes of displays (Fx, Fy and Fz axis forces, the saw blade rotation speed, the work piece travel speed, the cutting depth, cutting energy, active cutting power, noise, vibration, flow rate of cooling water, process status and error), buttons (start, main stop, program, reset, manual, data, analyzer, analyzer setup, energy reset, error clear and exit) and data fields (stone information, cutting parameters, constants, saw blade diameter, slice thickness and flow rate of cutting water).

All of displays show actual values. For example, active cutting power is real time value measured by energy analyzer. Desired values are written in data fields. But, it can be difference between desired and actual values. This status, it can result from measuring or control system errors.

The saw blade rotation speed, the work piece direction and travel speed, the saw blade vertical or horizontal position and flow rate of cooling water are controlled via manual window (Fig. 6). But whole of limit sensors are ineffective in manual mode. For example, when the saw blade moves up or down, the saw blade platform can exceed limit positions.



Fig. 6. Manual control window

All of data acquired by instrumentation system can be recorded on the data window (Fig. 7). This window is appeared as clicking "DATA" button placed on main window. In addition, active power and saw blade rotation speed graphs are drawn as real time.

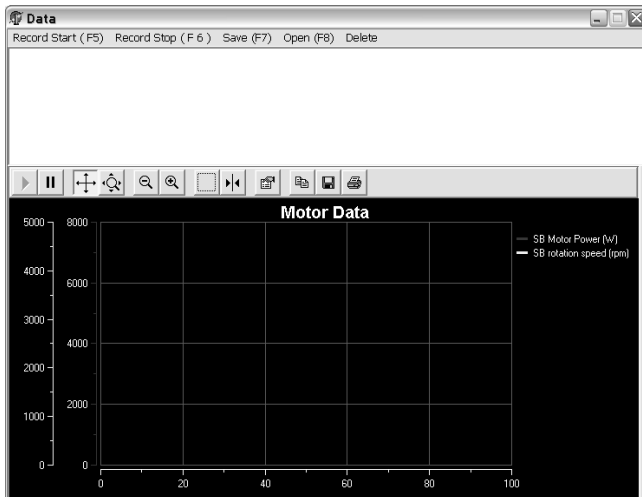


Fig. 7. Data window

Serial port's configurations are setup on serial communication window (Fig. 8). Also, serial communication is started with this window.

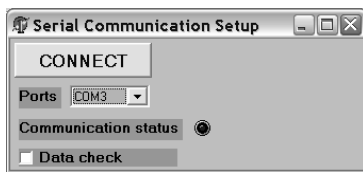


Fig. 8. Serial Communication window

When mathematical operations made as online, it can cause program errors in interface software. Therefore, these operations are performed as offline. Data files saved in "\*.txt" format are easily processed with spreadsheet software. Mathematical, graphical and statistical operations can be quickly performed on data files converted to spreadsheet.

### C. Designing new data acquisition system

The data acquired by energy analyzer (Shark 100) have enough precise for mining and mechanical investigations. Unfortunately, it is observed that, this precise will not be enough for energy optimization investigations.

Because of energy analyzer was designed for power monitoring applications, update time precise was not taken into account. Although, active power value is updated per 100ms, if active power demanded by saw blade motor is not out of a specific range, it is not updated.

Consequently, it is dedicated to design new data acquisition system for energy optimization applications. In new system, present substructure is protected but data acquisition card and power measuring system are completely changed.

The interface program is developed using LabVIEW software environment that is widely used in scientific studies [13-18]. To observe the data and control the parameters in the interface program, there exist various components. By means of the interface program; the saw can be positioned, the wagon can be moved in travel speed which is adjustable forward and backward, the saw motor can be controlled and cooling water speed also can be adjusted.

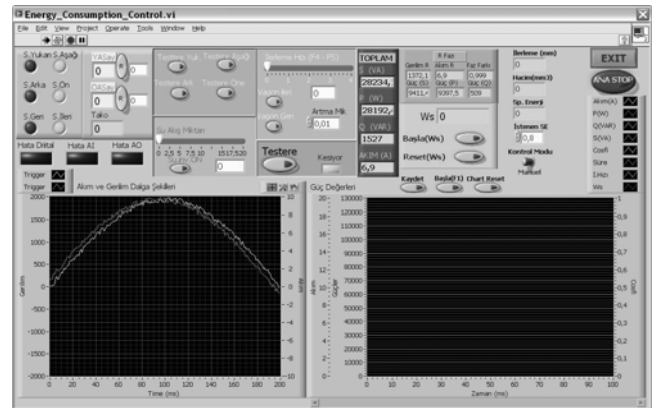


Fig. 9. The Interface software main window

In the experimental set, for all measurement and control functions, NI USB-6259 M series multi functional data acquisition (DAQ) card is used (Fig 10). DAQ card has 32 analog inputs with 16 bit resolution and 1,25MS/s sampling rate, 4 analog inputs with 16 bit resolution and 2,8MS/s sampling rate, total 48 digital I/O units in 1MHz speed and compatible with TTL/CMOS and 32 bit 80MHz counter/timer. The computer connection of the card is realized via USB terminal. To measure the electrical magnitudes of saw motor, current and voltage probes are used in data acquisition system (Fig 10). Thanks to these probes, the voltage and current values of motor can be converted to  $\pm 10V$  level and an electrical isolation is ensured between the card and networks. In Fig. 11 a block schema summarizing the new data acquisition and control system is given.

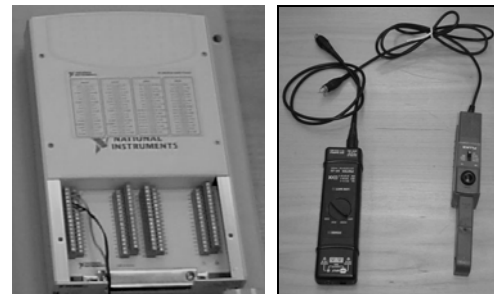


Fig. 10. Voltage and current probes

In LabVIEW, programs are designed or defined in graphics like preparing a flow chart instead of writing a code. Each function or procedure is stored in a program that is defined as VI (Virtual Instrument) and consists of two main components; front panel and block diagram. The front panel given in Fig. 9 belongs to a VI program that is designed to control the experimental set and acquire the experimental data used in this study. Front panels are the user interfaces containing data input and control components. Block diagrams are the panes where the functions are defined graphically (Fig 12). A block diagram may contain one or more sub VI that may be made similar to sub-procedure in text base programs. In this study, various sub VI programs are used for duties such as calculating the saw motor energy values in the designed main VI program.

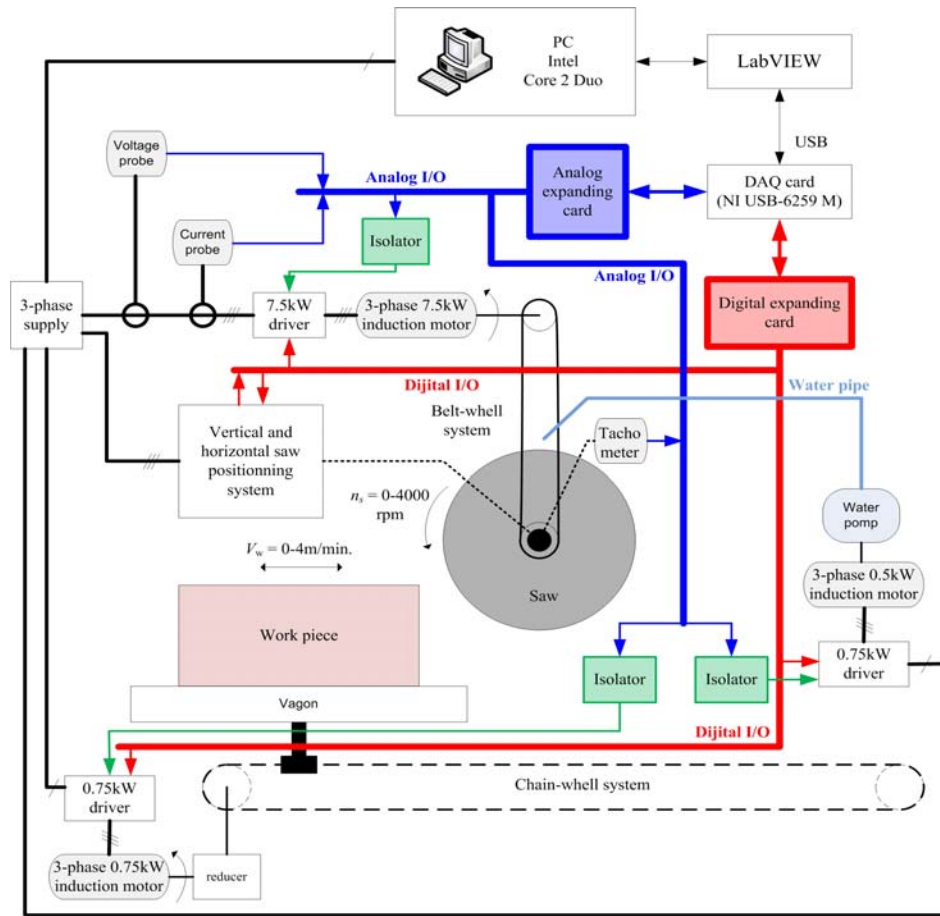


Fig. 11. Block schema of new DAQ system

In the block diagram cross section belongs to main VI program given in Fig. 12, we can see a section where the components that are used to read the saw motor current and voltage signals from analog inputs of the DAQ card are located. Here, the current and voltage signal coming from the card are sampled and from the sampled data, zero passing points are determined. After the zero passing points are determined, 200 samples are taken from each signal and sampling is stopped. The data related to current and voltage is transmitted to sub VI program named "Energy Analyzer.vi" to calculate the current and voltage, active, reactive and apparent powers and power factor.

#### IV. EXPERIMENTAL RESULTS

In this section some experimental results acquired with old and new interface software are presented. In old interface, Bilecik beige marble is used for cutting experiments. To observe the effect of rotation and travel speed, twenty experiments are made. In new interface, Afyon white marble is used for cutting experiments. To observe the effect of travel speed and saw rotation speed, twelve experiments are made.

In all experiments cutting depth and flow speed of cooling water are fixed respectively  $d=50$  mm and  $f_w=12l/min$ . In Table 1, cutting parameters are given for each experiment.

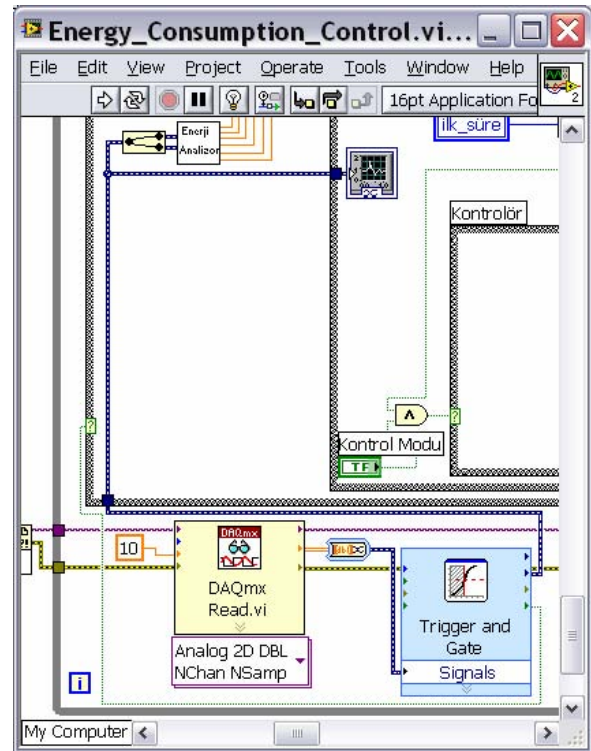


Fig. 12. Analog reading section of main VI block diagram

Table 1. Parameters of cutting experiments

Number	Old system		Old system	
	Saw rotation speed	Travel speed	Saw rotation speed	Travel speed
1	1432rpm	0.3	1350rpm	0.3
2		0.4		0.5
3		0.5		0.7
4		0.6		0.9
5		0.7		0.3
6	1910 rpm	0.3	1400rpm	0.5
7		0.4		0.7
8		0.5		0.9
9		0.6	1450rpm	0.3
10	0.7	0.5		
11	2384 rpm	0.3	1500rpm	0.3
12		0.4		0.5
13		0.5		
14		0.6		
15		0.7		
16	2864 rpm	0.3		
17		0.4		
18		0.5		
19		0.6		
20		0.7		

A. Analysis process

Cutting operation is realized with movement of work piece towards to fixed saw. When the movement directions of saw and work piece given in Fig. 13 is considered, down-cutting position is valid. All cutting tests in this study are realized in the below cutting position.

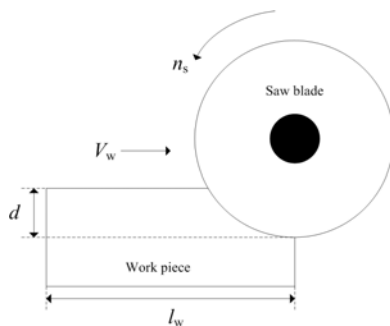


Fig. 13. Cutting mechanism

The data record in realized tests commences when the work piece touches to the saw and continues until the contact of saw axis with the work piece ceases. The energy account is made depending on the active power values obtained from the tests. The active energy is equal to area below the power curve. Total energy used in cutting can be determined with the below integral account. [20].

$$E_{total} = \int_0^T p(t) \cdot dt \quad (6.1)$$

Here,  $E_{total}$  indicates cutting energy (Ws),  $p(t)$  instant active power demand of motor (W) and  $T$  cutting time (s). The above given integral account is realized numerically. In other words, instant energy values calculated by multiplying active power values by sampling time are continuously being added and so total cutting energy is obtained. The calculated cutting energy values are converted to Wh unit in order to be more meaningful.

For specific cutting energy calculation defined as energy consumed per unit volume, the following formula is used [20].

$$SE = \frac{W_{total}}{q_w} \quad (6.2)$$

Here,  $SE$  indicates specific cutting energy (Wh/m<sup>3</sup>),  $w_{total}$  total cutting energy (Wh) and  $q_w$  total volume of channel opened by the saw (m<sup>3</sup>). In Fig. 14, channels opened by the saw on the work piece are seen.

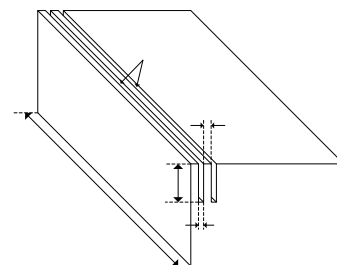


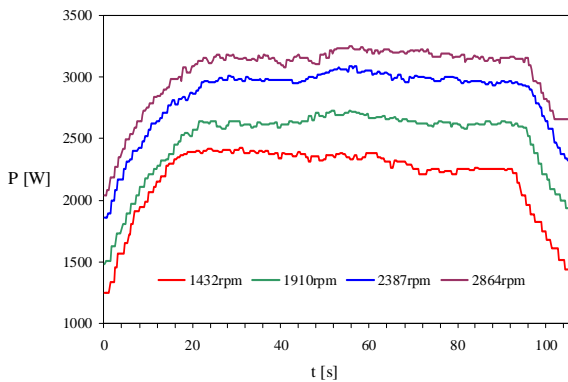
Fig. 14. Work piece and cutting channels

$$q_w = a_d \cdot d \cdot l_w \quad (6.3)$$

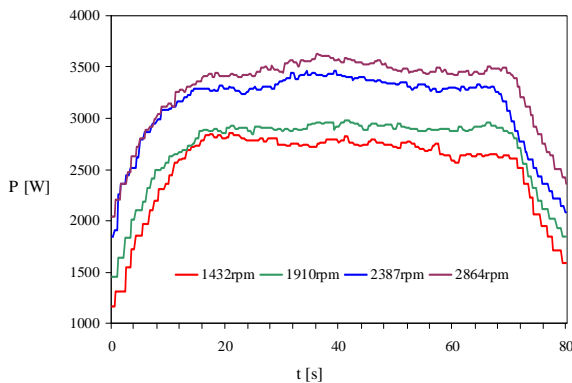
Channel volume ( $q_w$ ) is calculated with the above formula. Here,  $l_w$  indicates the length of work piece,  $d$  cutting depth and  $a_d$  channel width.

**B. Results of old system**

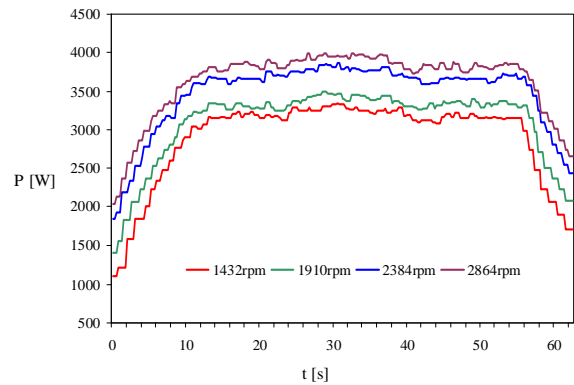
*Effect of rotation speed on saw motor active power:* The effect of rotation speed on active power is examined for 0.3, 0.4, 0.5, 0.6, 0.7m/min. (Fig 15-a, b, c, d and e). It is observed that increasing in rotation speed increases the active power. When saw started to cutting, demanded active power increases. During saw fully inputted to rock, demanded active power increases. During saw fully inputted to rock, demanded active power nearly stayed fixed value. To the saw motor is sufficiently loaded for high travel speed, effect of rotation speed on active power is little due to low travel speed. Thus, although increasing active power is clearly observed for low travel speed (Fig 15-a and b), it is not observed for high travel speed (Fig 15-e).



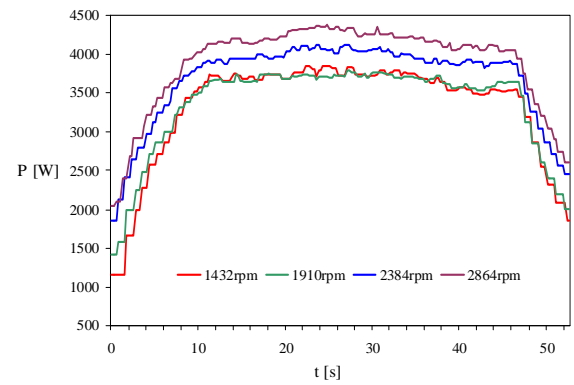
(a)



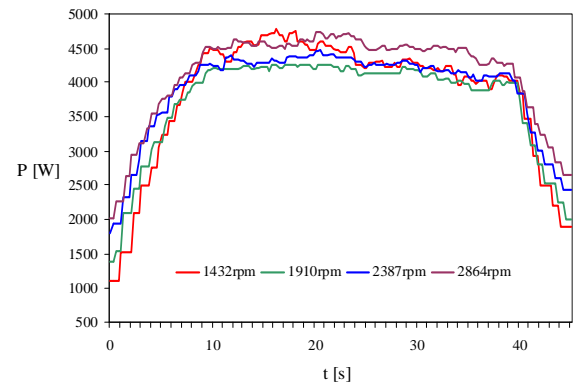
(b)



(c)



(d)



(e)

Fig. 15. Effect of rotation speed on active power (a)0.3m/min., (b)0.4m/min., (c)0.5m/min., (d)0.6m/min. and (e)0.7m/min.

*Effect of travel speed on saw motor active power:* The effect of travel speed on active power is examined for 1432, 1910, 2387, 2864rpm. (Fig 16-a, b, c, and d). It is observed that increasing in travel speed increases the active power. The travel speed effects cutting time. Therefore, increasing in travel speed decreases the cutting time. Travel speed quickly increase saw motor active power for 0.7m/min. thus, front and back slope of active power curve is more than low travel speed (0.3, 0.4i 0.5m/min.).

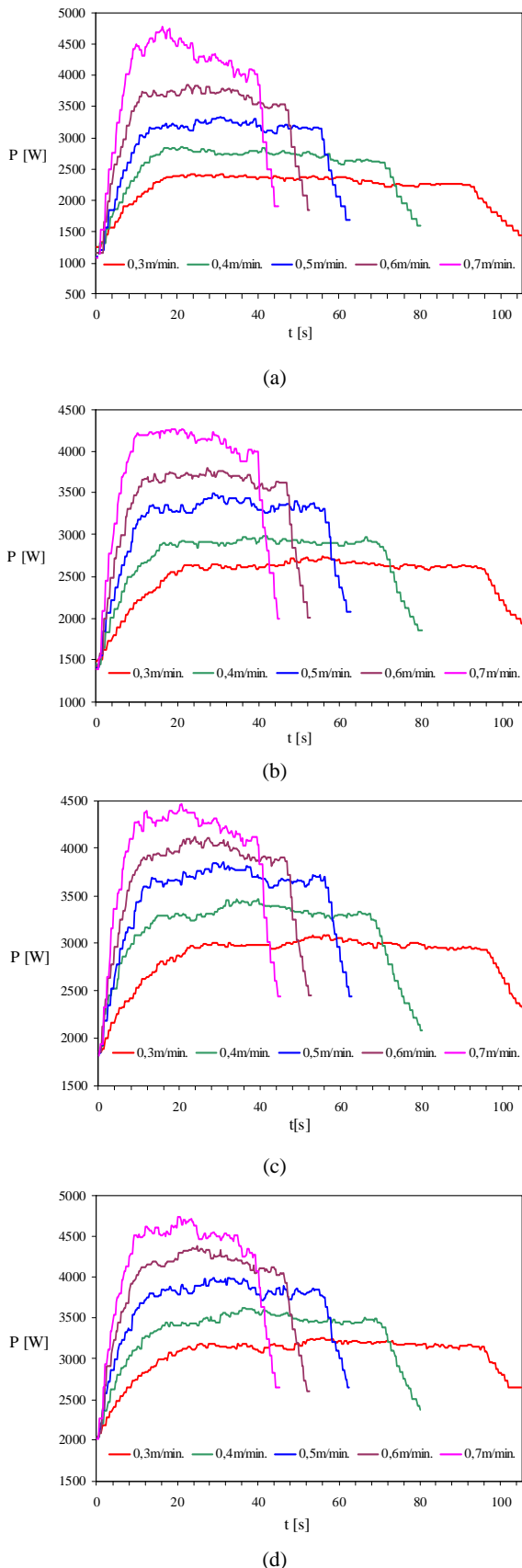


Fig. 16. Effect of travel speed on active power (a)1432rpm, (b)1910rpm, (c)2387rpm and (d)2864rpm.

*Specific energy analysis:* With increase of rotation speed, specific cutting energy also increases. Specific cutting energy demonstrates a marked increase especially in low travel speeds (0.3 and 0.4 m/min.) (Fig. 17-a). Increase in rotation speed (provided that travel speed will remain fixed) will cause more energy consumption unnecessarily as well as it will speed deformation of sockets. For this reason, rotation speed must be kept in a value most convenient for the cut marble.

According to the analysis, increase in travel speed decreases the specific cutting energy. While increase in travel speed increases the active power demand, it causes decrease in cutting time. Decrease in cutting time naturally decreases the specific cutting energy. On the other hand, for all rotation speeds (1432, 1910, 2385 and 2864rpm), values of specific cutting energy come very close to each other after some definite value of travel speed (Fig. 17-b). The said becoming closer point in graphics can be defined as region where the travel speed value gets its optimum value.

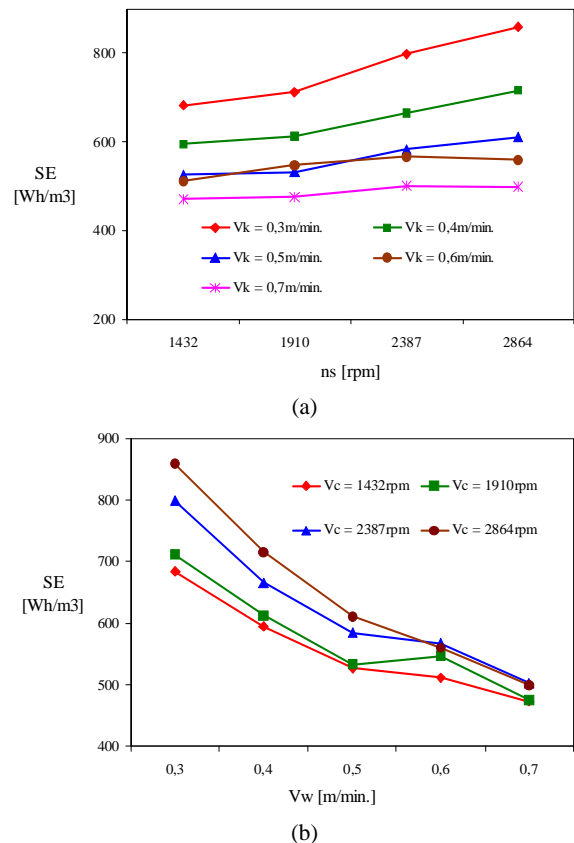


Fig. 17. Effect of (a)-saw rotation and (b)-travel speed on specific energy

When the graphics showing the effect of saw rotation and travel speeds on specific cutting energy are examined together (Fig. 17-a and b), it can be seen that the effect of travel speed on specific cutting energy is greater than the saw rotation speed. This is very clear from incline of graphic curves. For this reason, adjustment of travel speed rather than speed of



saw rotation will be more economical and easy approach.

### C. Results of new system

*Effect of rotation speed on saw motor active power:* The effect of rotation speed on active power is examined for 0.3, 0.5m/min. (Fig 18-a and b). It is observed that increasing in rotation speed increases the active power. Although, time interval is greater 250ms in old interface, it is less 40ms in new interface. Thus, experimental data acquired with new interface are showed that new system is more precise than old system.

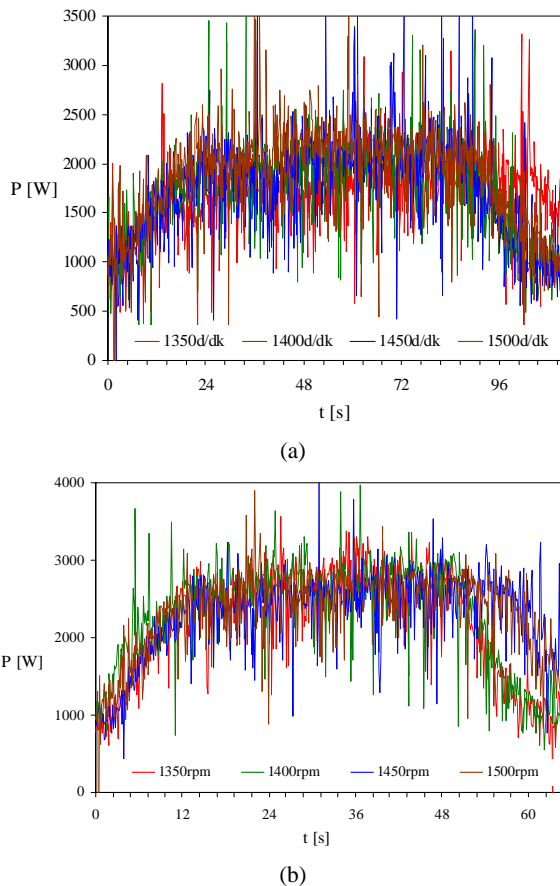


Fig. 18. Effect of saw rotation speed on active power (a)0.3m/min. and (b)0.5m/min.

*Effect of travel speed on saw motor active power:* The effect of travel speed on active power is examined for 1450, 1500rpm. (Fig 19-a and b). It is observed that increasing travel speed increases the active power. Active power demand is approximate 2000W level for 0.3m/min. For high travel speeds (0.7, 0.9m/min.) active power demand is approximate 4000W level. Effect of travel speed on active power is more than effect of rotation speed.

### D. Comparing of old and new system:

When old and new systems are compared, it is seen that new data acquisition system is more precise than old system. In old system, electrical parameters of saw motor are measured with energy analyzer designed for electrical

parameters of huge loads such as electric plants, factories etc.

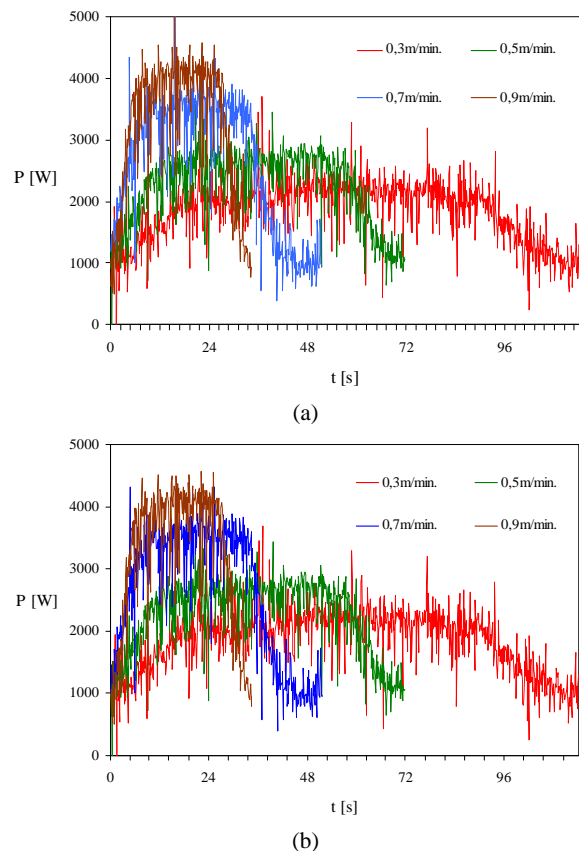


Fig. 19. Effect of saw rotation speed on active power (a)1450rpm and (b)1450rpm

To energy analyzer is designed for huge loads, it is understood that it will not used for energy optimization applications. In addition, to the energy analyzer and computer communicated via serial terminal, data transfer rate was slow (maximum 10 data per second). Although, active power value is updated per 100ms, if active power demanded by saw blade motor is not out of a specific range, it is not updated. So, sometimes time interval of data has increased to 1-2 second. In new system, time interval of data can be decreased from 1-2 second to 40 millisecond. The new system designed with LabVIEW (Laboratory Virtual Instrument Engineering Workbench) would be used developing controllers arranged travel and/or rotation speed.

## V. CONCLUSION

In this study, a computer controlled block cutting machine is presented. In addition, a LabVIEW based DAQ system designed for energy optimization is presented. Performances of DAQ systems are compared with experiments performed in some cutting parameters. In this study, the following results are obtained;

- Marble cutting experiments can be easily, speedily, precisely and reliably performed with PC based block-cutter and lots of data can be recorded as real time.

– When old and new systems are compared, it is seen that new DAQ system is more precise than old system. So the new system designed with LabVIEW would be used developing controllers arranged travel and/or rotation speed.

– The travel and saw rotation speeds have significant effects on cutting energy. With determination of optimum values of travel and saw rotation speeds, it is clear that the energy will be able to be used in productive manner. Even a saving in rate of 10% in energy consumption will bring significant benefit for Afyonkarahisar of which half of industry is established on marble treating.

– It is observed that the effect of travel speed on specific cutting energy is greater than the saw rotation speed. So arranging travel speed is economical way due to cost of saw motor driving.

– If the cost of speed control units can be decreased, driving saw motor can be made economical in the future. With optimization of saw rotation speed in addition to travel speed, more productive and high quality controllers that ensure securer operation will be developed.

#### ACKNOWLEDGMENT

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