ÇUKUROVA UNIVERSITY
INSTITUTE OF NATURAL AND APPLIED SCIENCES

MSc THESIS

İbrahim Saffa GÜNER

DETERMINED THE OPERATION MODES ON COMPACT HYDRAULIC EXCAVATOR AND THEIR EFFECTS OF FUEL CONSUMPTION AND HYDRAULIC SYSTEM IN REAL WORKING CONDITION

DEPARTMENT OF AUTOMOTIVE ENGINEERING

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We certify that the thesis titled above was reviewed and approved for the award of degree of the Master of Science by the board of jury on 10/06/2019

…………………………………	……………………………………….	……………………………………
Assoc. Prof. Dr. Hasan SERİN	Assoc. Prof. Dr. Mustafa ÖZCANLI	Asst. Prof. Dr. Ahmet ÇALIK
SUPERVISOR	MEMBER	MEMBER

This MSc Thesis is written at the Department of Automotive Engineering, Institute of Natural and AppliedSciences of Çukurova University.
Registration Number:

Prof. Dr. Mustafa GÖK
Director
Institute of Natural and Applied Sciences

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ABSTRACT

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: Assoc. Prof. Dr. Mustafa ÖZCANLI
: Asst. Prof. Dr. Ahmet ÇALIK

In this thesis, the effects of the actual operating conditions of the compact hydraulic excavator on the hydraulic system and fuel consumption were investigated. In this context, hydraulic pressure, hydraulic flow, instant fuel consumption, attachment cycle time values and average fuel consumption values were determined. For the compact hydraulic excavator, hourly fuel consumption and cycle time values were analyzed. The hydraulic pressure and flow values of the piston and gear pump are presented in the study depending on the time. Separate tests were carried out for operation modes. According to the data obtained, system limit values were determined. Cycle time values of machine attachment movements were obtained and the suitability and efficiency of operation modes were determined. The effects of trench digging, straight travelling, soil levelling and standby idling on the system and fuel consumption have been demonstrated. According to all data, results are presented for efficient operation modes.

Key Words: Compact Hydraulic Excavator, Fuel Consumption, Hydraulic System, Operation Mode, Cycle Time

ÖZ

YÜKSEK LİSANS TEZİ

GERÇEK ÇALIŞMA KOŞULLARINDA KOMPAKT HİDROLİK EKSKAVATÖR ÜZERİNDEKİ ÇALIŞMA MODLARININ BELİRLENMESİ, MODLARIN YAKIT TÜKETİMİ VE HİDROLİK SİSTEME ETKİLERİ

İbrahim Saffa GÜNER

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: Doç. Dr. Mustafa ÖZCANLI
: Dr. Öğr.Üyesi Ahmet ÇALIK

Bu tez çalışmasında, kompakt hidrolik ekskavatörün gerçek çalışma koşullarının hidrolik sistem ve yakıt tüketimi üzerindeki etkileri anlık olarak incelenmiştir. Bu kapsamda, hidrolik basınç, hidrolik debi, anlık yakıt tüketimi, ataşman cycle time değerleri ve ortalama yakıt tüketim değerleri belirlenmiştir. Kompakt hidrolik ekskavatör için saatlik yakıt tüketimi ve cycle time değerleri analiz edilmiştir. Çalışmada pistonlu ve dişli pompa ile hidrolik sistemin basınç ve debi değerleri zamana bağlı sunulmaktadır. Operasyon modları için ayrı testler yapılarak incelenmiştir. Elde edilen datalara göre sistem limit değerleri belirlenmiştir. Makine ataşman hareketlerinin cycle time değerleri elde edilerek operasyon modlarının uygunluk ve verimliliği belirlenmiştir. Hendek kazma, düz yürüyüş, toprak tesviye ve rölanti durumlarının sistem ve yakıt tüketimi üzerindeki etkileri ortaya konmuştur. Elde edilen tüm verilere göre verimli operasyon modları için sonuçlar sunulmuştur.

Anahtar Kelimeler: Kompakt Hidrolik Ekskavatör, Yakıt Tüketimi, Hidrolik Sistem, Çalışma Modu, Çevrim Süresi

GENİŞLETİLMİŞ ÖZET

Bu tez çalışmasında kompakt hidrolik ekskavatörün gerçek çalışma koşullarının, yakıt tüketimi ve hidrolik sistem üzerindeki etkileri anlık olarak gözlemlenmiştir. Bu çalışma kapsamında makinenin hareket kabiliyetini belirlemek için hareket hızları ölçülmüştür. Verimli çalışma aralıkları belirlenmiştir.

Tezin başlangıç kısmında iş makinası sektörünün ülke ekonomilerindeki yeri, çevre kirliliğine etki eden emisyonları, emsiyonları azaltmak için uygulanan yöntemler, makine seçiminde en önemli parametreler, pazarın düşük yakıt tüketimi ve verimli çalışma talebi ve kompakt ekskavatörün iş makinesi pazarından aldığı oranın her geçen gün artması gibi konular ele alınmıştır.

Yakıt tüketimi konusunda başlıca tanımlar verilmiştir. Bu kapsamda içten yanmalı motorların tarihçesi kısaca özetlenmiş çalışma mekanizmaları üzerinde durulmuştur. Yine mobil uygulamalarda yakıt sisteminin temel birleşenleri üzerinde açıklamalar yapılmıştır. Tezin materyal metod kısmında test makinesinin motor ve yakıt sistemi detaylı olarak açıklanmıştır.

Tez çalışmasında kullanılan başlıca ekipmanlar sırasıyla hidrolik debimetre, hız ölçer, endüstriyel basınç ileticisi, yakıt tüketimi ölçüm cihazı ve kompakt ekskavatördür. Ayrıca bu kısımda test yapılacak kompakt ekskavatörün özellikleri detaylı olarak sunulmuştur. Bu amaçla çalışma prensipleri ve üzerinde bulunan komponentler işlevleri ile birlikte detaylandırılmıştır.

Metod kısmına geldiğimizde ise tez çalışmasında kullanılacak olan kompakt ekskavatörün verimli çalışması için sistem bakımları yapılmıştır. Bu tez çalışmasında test kriterleri için sahada gözlemlenen hareketler belirlernerek kullanılmıştır. Bu kapsamda test sırasında kazı, tesviye, yürüyüş ve rölanti olarak dört ana durum belirlenmiştir. Test uygulanırken izlenecek yöntem bu şekilde belirlenmiş, olası sürücü kaynaklı farklılıkları minimuma indirmek amacıyla tek sürücü ile belirlenen 1400-2600 arası devirlerde testler tamamlanmıştır.

Uygulama öncesi kompakt ekskavatöre gerekli bakımlar yapılarak optimum yakıt tüketim değerlerini elde etmek amaçlanmıştır. Hazırlık aşamasından sonra kompakt ekskavatör belirlenen devirlerde test etmek üzere kazı alanına götürülerek çalışma yapılmıştır. Çalışma sırasında hidrolik debi, hidrolik basınç ve yakıt tüketimi değerleri belirlenen test senaryosuna göre anlık olarak kayıt altına alınmıştır. Sistemin çalışma sırasında göstermiş olduğu tepkiler gözlemlenmiştir.

Kompakt hidrolik ekskavatör her devir için bir saat boyunca test edilmiştir. Anlık yakıt tüketimi, ortalama yakıt tüketimi, hidrolik basınç ve hidrolik debinin yanı sıra boom açma ve kapama, kol açma ve kapama, kova açma ve kapama, ve üst şase dönüş süreleri ölçülerek performans karşılaştırmasına imkan sağlanmıştır.

Ekskavatörde test yapılarak hidrolik sistem, yakıt tüketimi ve performans değerlerinin belirlenmesinin ardından verimli çalışma devirleri belirlenerek çalışma modları elde edilmiştir. Yakıt tüketim değerleri 0.074 kg/kWh ile 0.199 kg/kWh arasında test devirlerine göre değişmektedir. Böylece kazı, yürüyüş, tesviye ve rölanti aşamalarının karma yakıt tüketimi üzerindeki etkileri gözlemlenmiş, makinanın hidrolik çalışma basıncı üst limiti 230 bar olarak gözlemlenmiş, hidrolik debi pistonlu pompalar için 34 lt/dk dişli pompa için 27lt/dk maksimum olarak belirlenmiş, hareket hızları her ataşman için maksimum ve minimum elde edilmiş, sürücü kaynaklı ortaya çıkacak ekstra yakıt tükeminin önüne geçilmesi amacıyla operasyon modları ortaya konmuştur.

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LIST OF ABBREVIATIONS AND NOMENCLATURE

SI	: Spark Ignition
CI	: Compressed Ignition
TDC	: Top Dead Center
BDC	: Bottom Dead Center
EDAS	: Ecologic Driver Assistance System
ROLS	: Remote Optical Laser Sensor
IEC	: International Electrotechnical Commission
MTBF	: Mean Time Between Failures
NBR	: Nitrile Rubber
daN	: Dekanewton
MCV	: Main Control Valve
JCMAS	: Japanese Construction Mechanization Association Standard
RPM	: Revolutions Per Minute

1. INTRODUCTION

The construction machinery industry is critical in the development of the industries of countries. The importance and share of the construction machinery sector in the global world economy is increasing day by day. As in the world, in the reports prepared by the European Union Commission, the importance of the construction machinery sector has been emphasized in the developing industry. The growth of the construction and mining sector, developing municipalities, and the construction of infrastructure systems, the credit support given to the construction sector and low interest rates are the main factors in the rapid growth of the construction machinery sector in Turkey. Although it is one of the most affected sectors from the crisis as it is all over the world, the construction machinery sector holds an important place in the Turkish industry. As Chinese brands began to come to this region market, the sales of European machines were also directly affected.

Environmental awareness around the world, a large number of private institutions and government plans, initiatives and campaigns aimed at promoting sustainability, are among the rising issues of popularity. All the brands in the construction sector try to provide high efficiency equipment in the field of construction, increasing energy cost and environmental awareness.

Governments and the construction sector impose restrictions on reducing emissions and ensuring sustainability, using energy efficiently. The largest energy consumption in the construction sector occurs in heavy-duty machines such as, hydraulic excavators, cranes and bachoe-loader etc. According to research, Fossil Energy Fuels are increasingly expensive, and energy use is expected to lead to costs and environmental degradation that cannot be overcome for future generations. For this reason, governments want to reduce fuel consumption and emissions to minimum levels. Otherwise, this great energy consumption in the construction sector will go to a point where environmental problems can not be solved. Governments determine policies for the work to be done in the implementation phase by taking this into consideration; selecting the appropriate machine and avoiding the use of inefficient heavy machinery, and using machines with maximum efficiency.

In construction companies, fuel consumption and maintenance costs are among the subjects of machine selection. Fuel consumption directly affects profit rates. The cost of fuel consumption constitutes a significant part of the overall cost of a project. Efforts are being made to lower costs, but fuel prices in the global market are still making it difficult to capture the desired levels. In this case, the construction costs of companies increase as machines work, and focus on reducing fuel consumption. However, machines with low fuel consumption values are expensive because they are advanced technology products. Construction companies are hesitant to buy these machines because they are expensive.

Alternatively, to reduce fuel consumption, optimisation can be performed on the engine and the driving style, so there is no need to make extensive changes to the machine. This method is seen as the easiest and cheapest way to reduce fuel consumption in the machine. Otherwise, the cost of the changes to be made is very high.

Construction machinery reacts differently to various operating conditions. For example, fuel consumption of a compact excavator under low, medium and heavy loads varies considerably. The fuel consumption depends on many factors (operator, ground structure, environmental etc.), it is very difficult to calculate theoretically. However, under the same conditions, necessary optimizations can be made with field tests.

In addition, the choice of hydraulic compact excavator in the sector is increasing day by day in line with the aim of reducing emissions and fuel consumption values in order to protect and sustain the environment. The use of compact hydraulic excavators is increasing day by day in areas such as urban transformation, infrastructure work, agriculture, landscaping. Based on the choice of compact hydraulic excavators, there is a need to work faster and more efficiently in projects with increased labor costs. In addition, because of the compact structure of these machines, it is possible to work comfortably in narrow spaces. Therefore, the test and optimization studies to be carried out in this thesis will be done in the compact excavator you can see in Figure 1.1.

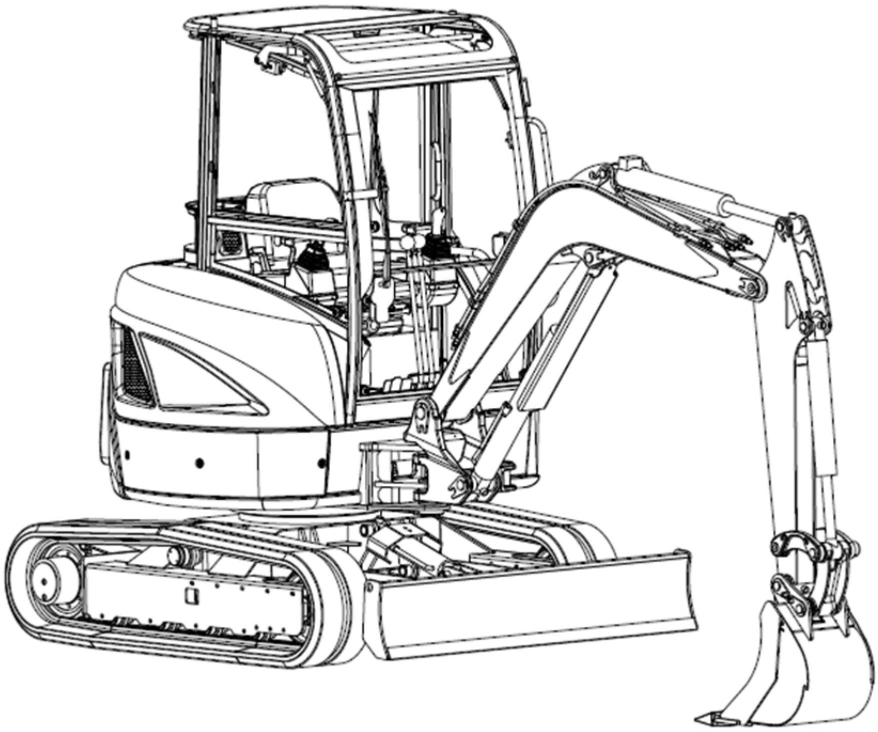

Figure1.1. Compact Hydraulic Excavator MST M38 (Mst User Maintenance Guide,2016)

In this study, it is aimed to determine the correct engine operating rpm to reduce the fuel consumption values. In this scope, the fuel consumption values of the hydraulic compact excavator at different engine operating rpm were tested in real working conditions. The changes in the hydraulic system of the compact excavator were observed in different engine operating rpm. At different engine rpm, the machine's boom, arm, bucket and swing turn speeds were determined.

Considering all this information, it is aimed to determine the economical driving modes.

2. PRINCIPLES OF FUEL SYSTEMS

2.1. Introductıon to Engines

The internal combustion engine is advanced machines that convert the stored fuel chemically into mechanical energy as a result of combustion reactions and transmit it through the shaft. In the combustion chamber, the chemical energy of the fuel is converted into thermal energy by reacting with air. As a result of the thermal state of the energy, the gas temperature and pressure in the engine increase and they try to expand on the elements of the mechanical system. The expansion event is transformed into action with the main elements of the engine and transmitted to the crank shaft. The mechanical energy of the crank shaft is transmitted through the powertrain elements and used for the desired movement capability. This is known as propulsion for vehicles where motors are used. In addition, there are stationary motors for applications such as generators and portable motors for other different applications.

Internal combustion engines usually operate with the piston movements it has. These engines can have 16 or more cylinders. In the same way, these cylinders can be applied in different order. It has a wide range, from very low-power engines to massive-sized engines. Since many engine manufacturers from the past to the present produce different sizes, geometry, styles and working characteristics of engines according to their needs, there is no definite limit to the engines.

The development of internal combustion engines began in mid-1800's and continued to develop on the same axis as the automotive industry. However, the simple examples of the first internal combustion engines are based on the 1600's. Since these first vehicles are not practical machines that can be used, and because the material and fuel technology are not developed sufficiently, they have taken their place in history as steam-powered prototypes. In the first engine trials, gunpowder and different phases of fuels were used. The industrial revolution and the desire to spread rail networks all over the world have had a major impact on the development of motor technology since the first half of the 1700's.

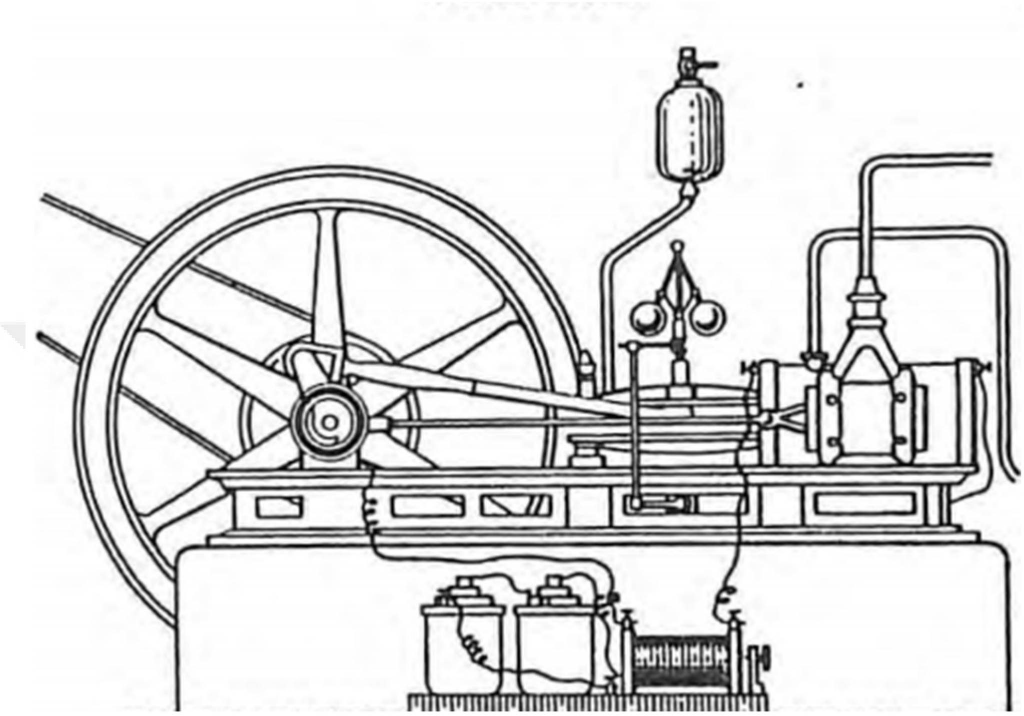

Figure 2.1. Lenoir Gas Engine (Stone, Richard, 1992)

The first internal combustion engines, in general, can be called the atmospheric engine. These engines are usually single cylinder and piston atmospheric motors. In these combustion engines, gunpowder was used instead of the fuel types available today. After the combustion reaction, high-temperature exhaust gas was released in the cylinder. After these first primitive engines, the cylinder chamber was closed and the compressed gas was cooled and condensed. As a result of the cooling of the gas, the vacuum effect occurs in the combustion chamber. Hereby, the pressure difference between the outside atmospheric pressure and the vacuum occurs. The movement that occurs as a result of pressure difference is connected to the system and the required work is done.

In addition to all these developments in Europe, when we arrived in the mid-1800's, the United States provided the necessary support for the development of motor technologies. Crude oil, one of the milestones in the development of engine technology, was found in Pennsylvania in the late 1850s and produced efficient fuels that could be used in developed engines. One of the biggest obstacles to the development of engine technology was the lack of appropriate fuel. Fuels such as coal, gunpowder etc. were not as suitable as crude oil to use and develop in the engine. It took a long time for the fuel industry to develop and return the first crude oil to the fuels we use today, such as gasoline and diesel. Despite all of this, crude oil products began the development process in the 1860s and continued to develop with the internal combustion engine.

The early years when the engine was used in vehicles, internal combustion engines were competing with steam and electric motors. However, the short range provided by the electric motors, and the long time required for the first operation of the steam engines has been effective in the choice and development of internal combustion engines. That's why, 20.century is the golden age of the internal combustion engine in general. (Pulkrabek, Willard W.,1997)

2.2. Early History to Engines

In the 1900s, internal combustion engines were produced in many numbers and varieties. By the process of testing the engines, the development has increased exponentially. In addition to being reliable and successful, these engines work with complex and various mechanical systems.

The first usable engine we know of in the 1860s, It was invented by J.J.E Lenoir. Over the course of ten years, these engines continued to be produced, but they were no more than 5% of their efficiency. The efficiency of the engine developed by Otto-Langen in 1867 was 11% is shown Figure 2.2. This was a much more efficient engine than the previous engine. Introduced this engine has been produced thousands of units in the next ten years. It was an atmospheric engine, invented by Nicolas A. Otto and Eugen Langen, acting against the force of vacuum. In this time period, engines were working on the same principle as today's four-stroke engines and so the modern engine design began to evolve. Even though many inventors worked on a four-stroke engine, Otto was able to produce the engine in 1876. In 1880s, internal combustion engines started to be used in automobiles.

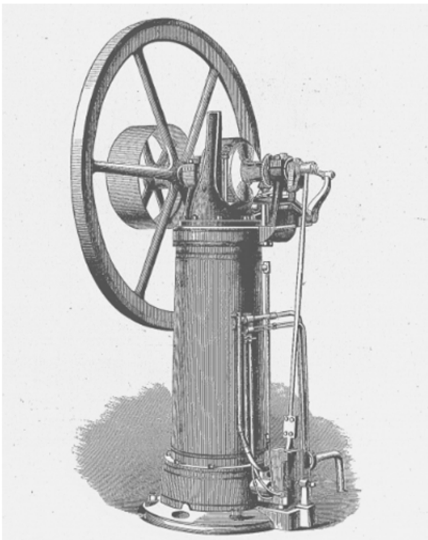

Figure 2.2. Otto-Langen Engine (Stone, Richard, 1992)

At the end of the nineteenth century, two-stroke engines have become available in these years and a large number of them have been produced and sold. When we arrived in 1892, Rudolf Diesel developed the compression ignition, which we know as a diesel engine is shown Figure 2.3. This progress has emerged as a result of Rudolf's work on solid fuel usage in the first prototype engines.

The first compression ignition engines were loud, huge and single-piston engines. Even though they were more efficient than engines with spark ignition system, they have not been used in vehicles for a period of time, since compact models were not produced. (Pulkrabek, Willard W.,1997)

Figure 2.3. Rudolf Diesel Engine (DIESELNEWS,2019)

2.3. Four Stroke Cycle Compression Ignition Engine

CI engines are machines that burn fuel by injecting it into fully compressed air that is absorbed in the combustion chamber. The combustion occurs spontaneously, along with sufficient pressure and temperature values, during the combination of compressed air with atomized fuel. Simply, burning does not happen with an external factor is shown Figure 2.4. As with four-stroke SI engines, all events of a cycle in CI engines occur in two crank cycles or four piston strokes. These four stroke engines can be explained as the absorption of air, the compression and heating of the air, the injection fuel and expansion of the fuel through combustion, and the release of combustion products.

Induction stroke is shown Figure 2.4, when the intake valve is open and the exhaust valve is closed, the piston moves away from the cylinder head. A depression occurs in the cylinder by the piston moving down. The magnitude of this depression depends on the cylinder dimensions, the inlet port and the speed of the piston. The pressure difference between the inside and outside of the cylinder, along with the air at atmospheric pressure moves and fills into the cylinder. The throttle valve, which is required to adjust the air fuel mixture in gasoline engines, is not required because there is no limit to the intake system in CI engines. It is enough to send pure air into the cylinder. Maximum depression during piston movements is around 0.15 bar. However, the average pressure inside the cylinder is 0.1 bar or less while the piston is outwards stroke.

Compression stroke is shown Figure 2.4, the piston moves towards the cylinder head while both inlet and exhaust valves are closed. The air in the cylinder is compressed in different proportions from 12 to 24 according to its normal volume. The average compression ratio from maximum to minimum for CI engines is around 16: 1. However, this depends on the size and speed of the engines. In the compression stroke, until the cylinder pressure reaches between 30 and 50 bar, the air charge at atmospheric pressure and temperature are reduced. Under normal conditions, compressed air in this way increases the charge temperature by at least 600 °C.

Power stroke is shown Figure 2.4, the diesel fuel is injected into the compressed and heated air at high pressure, while the inlet and exhaust valves are closed, the piston is almost at the end of the compression stroke. The fuel is injected atomized and properly into the cylinder, allowing the very small particles of liquid fuel to evaporate with the compression temperature. As a result, the piston reaches the lowest point in a very short period of time. In this case, the heat energy is released by efficient combustion and creates pressure on the piston. In the continuation of the expansion, the piston is pushed away from the cylinder head. It transmits the pressure above it to connecting rod as thrust. In this way thrust is transmitted the crank shaft as rotary motion.

Exhaust stroke is shown Figure 2.4, when it reaches the end of combustion and the piston reaches its lowest point, the exhaust valve opens. The piston changes the direction of movement after this phase and moves towards the cylinder head. The burnt and burning products in the combustion chamber are released to the atmosphere with the sudden opening of the exhaust valve at the end of the power stroke. the high pressure at the end of combustion increases the energy of the gases, allowing combustion products to be ejected quickly from the cylinder. This would be so fast that almost piston can't get to the gas. Figure 2.4 shows the order of four operating strokes in a four-cylinder engine and the effect of combined operating events on cylinder pressure and piston displacement. (Crolla,David A.,2009)

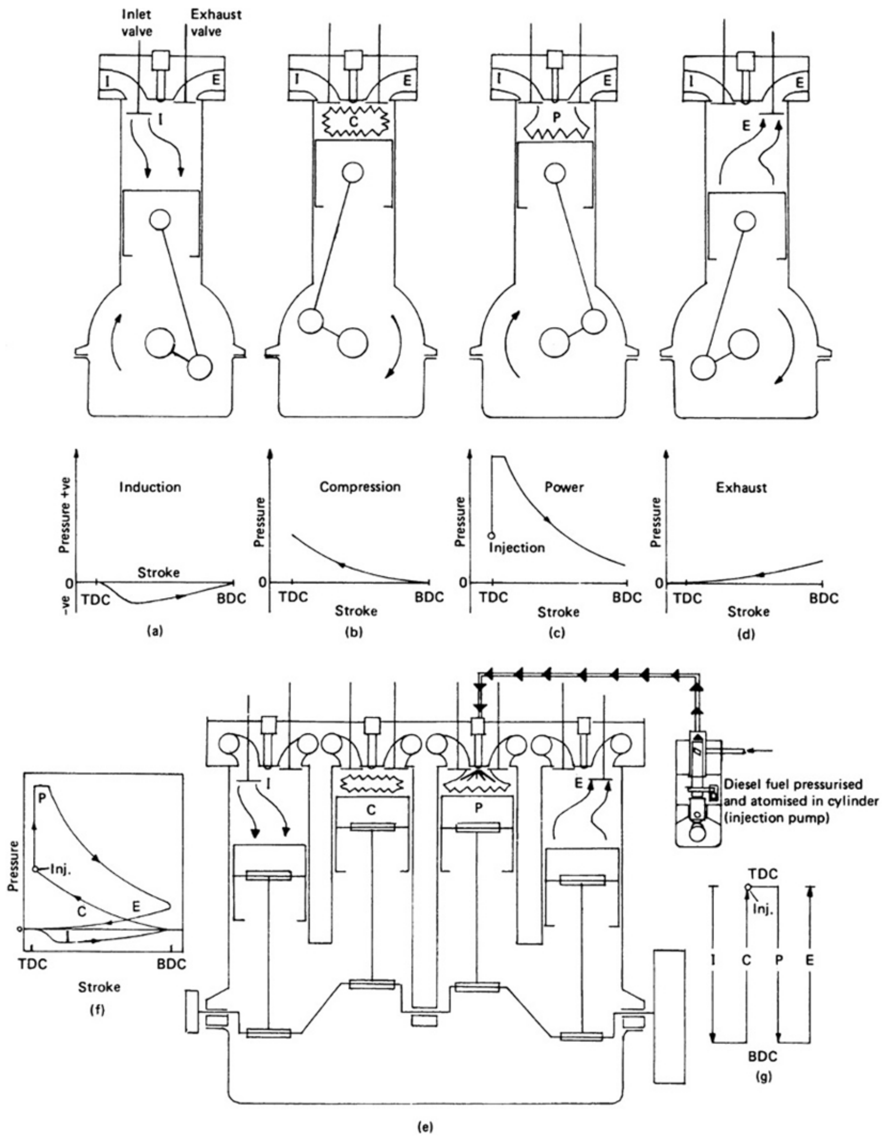

Figure 2.4. Four Stroke Cycle Diesel Engine (Crolla,David A.,2009)

2.4. Main Engine Components

In this section, the main parts of the engine will be defined. These parts will be explained below. To make it more understandable, Figure 2.5 and Figure 2.6 are also shown.

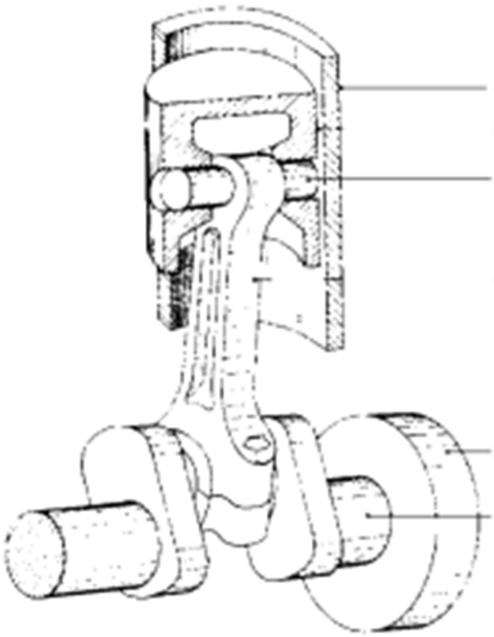

Figure 2.5. Pictorial View of Basic Engine (Crolla,David A.,2009)

The engine block in which the cylinders are located is made of aluminium or cast iron. As a result of the development of material technology, it can also be produced from different alloy materials. In the block of water-cooled engines, there are water channels around the piston. Air cooled engines have fins on the outer surface of the block.

Camshaft is a rotating shaft used to open and close valves at the right time within the engine cycle. It does this directly by mechanical or hydraulic connection. Camshafts were mounted on the head of the engine in the current engines, while the old engines were in the crankcase. Camshafts are produced of steel or alloy materials and are driven from the crankshaft by chain or belt. Camshaft turns half the engine speed in four-stroke engines.

Connecting rod is a critical component that connects the piston and rotary crank shaft. It is made of steel or alloy material. In some engine models, it can also be produced from aluminium.

Connecting rod bearing is a bearing-shaped piece that connects the connecting rod to the crankshaft.

Crankcase is part of the engine block closing of the rotating crankshaft. In most engines, the oil pan is part of the crankcase.

Crankshaft is a rotating part that allows the power obtained from the engine to be transmitted to the required places for use. The crankshaft is connected to the main engine block through the bearings. The pistons connected to the crank shaft through the connection rods rotate the crank shaft around the rotational axis. This rotation axis is also known as the crank radius. Most crank shafts are made of cast iron or steel.

Cylinders are circular cylinders that move reciprocally within the engine. Cylinder walls are very sensitive machined hard surfaces. Cylinders can be machined directly within the motor block and can be obtained by pressing from the soft metal block with hard metal sleeve

Exhaust manifold is a piping system that allows exhaust gases to be discharged from engine cylinders. The temperature of exhaust gas is very high, so it is made of durable material.

Exhaust system is the flow system used to remove exhaust gases from the cylinder, make them harmless and release them out. The exhaust system includes exhaust manifold to remove exhaust gases from the cylinder, thermal or catalytic converter to reduce emissions, muffler to reduce engine noise, and pipes to keep hot and toxic exhaust gas away from passengers.

Fan is used in most engine to increase air flow to the radiator and engine compartment, which takes the drive from the engine, and to remove the resulting heat. Fans can be mechanical and electrical. what's more, it can be operated continuously or it can be activated when necessary.

Flywheel is a heavy part connected to the crankshaft of the engine and rotating with inertia moment. Flywheel is designed to store energy and provide a large angular moment to stabilize the engine between power strokes.

Fuel injectors are parts that atomize the fuel at high pressure into the cylinder in diesel engines.

Fuel pump are electrically or mechanically driven parts that provide fuel to the engine from the fuel tank. In the latest manufactured vehicles, the electric fuel pump is preferred and located inside the fuel tank. In primitive engines, the fuel supply was provided by gravity, not by the pump.

Glow plug is the electrical resistors which heat the cold combustion chamber sufficiently for the combustion to occur and are mounted in the combustion chamber in diesel engines. The glow plugs turn off after the engine has started.

Head are parts that cover the cylinders, containing clearance volume. The head is usually made of cast iron or aluminium and are connected to the engine with bolts. Few engines have one piece of head. In today's diesel engines, parts such as camshafts and fuel injectors are mounted on the head

Head gasket provides sealing between the engine block and the head and is mounted with the same bolt. Generally, gaskets are produced from metal and composite materials and are recently used liquid gasket in the engines.

Intake manifold is piping system that transmits the absorbed air to the cylinders. It is made of cast metal, plastic or composite material. In some engines, intake manifold is heated to evaporate the fuel. (Pulkrabek, Willard W.,1997)

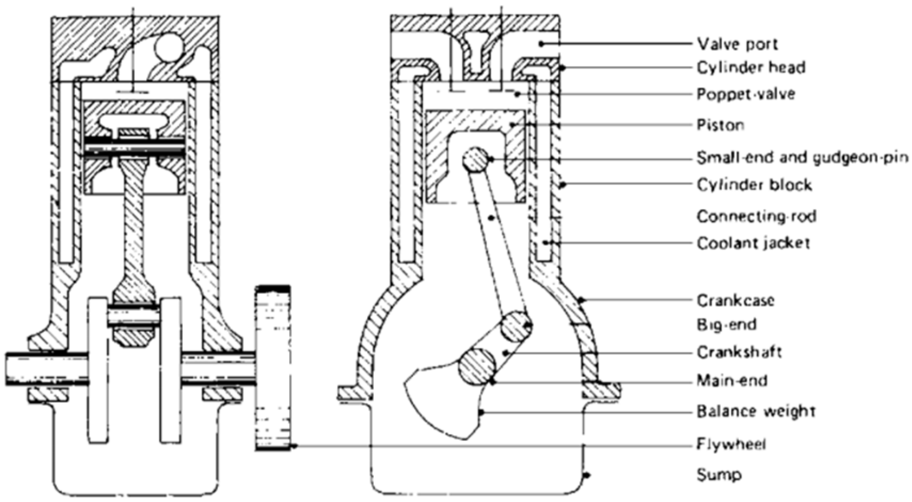

Figure 2.6. Sectional View of Basic Engine (Crolla,David A.,2009)

Main bearing are parts that connect the crankshaft with the engine block. The number of bearings is usually the number of pistons.

Oil pan is connected to the crankcase with bolts. It is also known as the oil crankcase in most engines.

Oil pump is the part that allows the oil to be transmitted to critical points that need to be lubricated in the engine. Although there are electric-powered oil pumps, mechanical pumps are widely used.

Oil sump is the oil reservoir of the engine lubrication system. It is usually known as part of the crankcase.

The piston is one of the important parts of the engine that transmits the forces in the combustion chamber to the rotating crankshaft and moves up and down in the cylinder. The bottom and side of the piston is called crown and skirt. Because the crown surface is a significant part of the combustion chamber, it is flat and high precision. Some piston types are produced in the form of bowl in the crown, which constitutes a large part of the clearance volume. The pistons are manufactured from different materials. Some manufacturers prefer high strength iron and steel, while others use aluminium. Steel and iron have sharper edges, tighter tolerances, fewer cracks, and less thermal expansion. On the other hand, aluminium pistons are lighter than steel and iron pistons, so less mass inertia is preferred than iron and steel. Even if composite material is used in some pistons, the crown part is still made of metal.

Piston rings are parts that enclose the piston and allow it to slide in the cylinder. On the piston, there are two or more fine-machined rings made of chrome steel. The main purpose of these is to prevent the gases in the combustion chamber from leaking through the piston and cylinder and going into the crankcase. There is another ring on the piston, except for these compression rings. This ring is an oil ring used to lubricate the cylinder and reduce excess oil consumption.

Radiator has a honeycomb structure, used to remove heat from the engine, the main element used in cooling the engine cooling fluid. It is mounted on the front of the engine and in the forward direction of the vehicle to provide more air flow to the radiators. In order to obtain enough air, the air is sent to the radiator through a fan that takes its power from the engine.

Starter is used to give the engine the first movement. Although there are many ways to give the engine the first movement, it is generally preferable to drive the flywheel with an electric motor. In small-scale internal combustion engines, when the power of the electric motor is taken from the battery, a different engine is used to provide sufficient power to the electric motor in large engines.

Throttle are parts installed in the intake system that control the amount of air and fuel. Some primitive stationary motors do not have throttle valve.

Intake and exhaust valves are the parts that ensure the continuity of the cycle, making the inputs and outputs within the cylinder on time. Valves are made of steel. The opposite surfaces that the valves cover are called seats and are produced from ceramics.

Water pump is used to circulate the coolant inside the engine and radiator. The pump usually takes its power from the engine mechanically. (Pulkrabek, Willard W.,1997)

2.5. Fuel System In Diesel Engine

The environment is becoming more polluted and lower fuel consumption is demanded in all vehicles that are used to reduce emissions and make resource use more efficient. In this scope, fuel is injected into the combustion chamber with different injection systems (direct or indirect) and pressures between 350 and 2050 bar to ensure efficient combustion, and this fuel is measured with high precision. In diesel engines, load and speed control must be controlled by the amount of fuel injected, regardless of the intake air flow control. Instead of the mechanically controlled fuel system previously used in diesel engines, electronic control systems are more widely used.

The main purpose of the fuel system is to provide the necessary fuel to the diesel engine. To perform this task, the injection pump prepares the fuel for injection at adequate pressure. The fuel is injected into the combustion chamber by passing through the fuel system components and forced into the injection nozzle at high pressure. In general, the fuel system consists of the following components: the governor, fuel tank, injection nozzles, fuel supply pump, high pressure tube, fuel filter and timing device. These components are mainly shown in Figure 2.7.

Combustion in a diesel engine is largely related to the amount of fuel injected and the injection method into the combustion chamber. At this point, the most critical are considerations about the efficiency of the fuel system: fuel injection timing, injection duration, the distribution of fuel in the combustion chamber, the first moment of combustion, total amount of injected fuel according to engine load and measured crank angle. As clearly seen, these issues interact with each other, optimizing all these aspects is critical for efficient operation of the diesel engine and fuel system. (Tschöke, H., 1999)

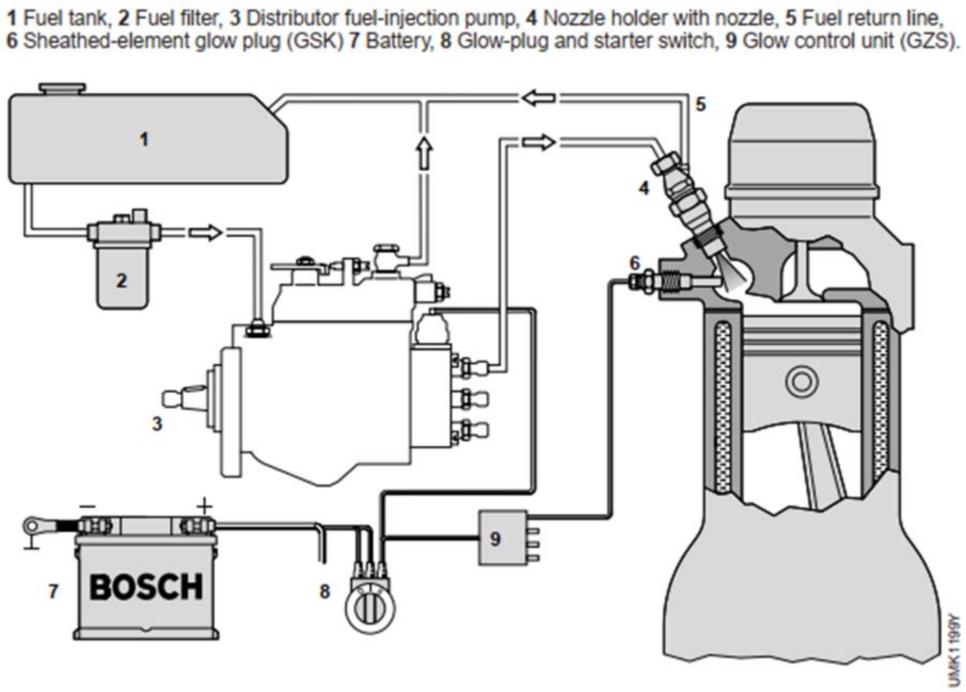

Figure 2.7. Fuel Injection System with Mechanically-Controlled(governed) Distributor Injection Pump (Tschöke, H., 1999)

The main functions of the diesel fuel system are as follows;

The fuel that is ready in the tank at low pressure passes through the fuel filter and passes to the required components at high pressure. This task is considered a subsystem of the low pressure circuit and usually consists of pre-filter parts, main filter, fuel filter and control valves. The low pressure circuit provides connection between the fuel tank and the high pressure fuel circuit supply, and also provides a return to low pressure parts through the connection lines. The important thing here is that pressure and flow values in low and high pressure lines and components must be precisely controlled and monitored.

Another issue is high pressure production and fuel distribution with the high efficiency during compression to the point of measurement or to an accumulator. At the point of efficient operation of the engine, both of the injection pressures in a stable and dynamic state must provide the necessary fuel. The amount of fuel required to be injected have to be distributed by making necessary checks despite leaks. This critical work is carried out by the high pressure pump and the accumulator integrated into the system. Valves are integrated into the system to control the flow and pressure in the fuel circuit. However, in advanced fuel system technologies, this is electronically controlled.

Precise measurement of fuel mass to be transmitted to combustion chamber in accordance with engine speed and load, and besides support by exhaust gas aftertreatment systems. Fuel metering in technological injection systems is achieved through electrical solenoid or valves installed directly to high pressure pumps or injectors.

Fuel pressure is optimized and sprayed to prepare the fuel to the combustion chamber for the mixture, at the right time and position to be distributed. The fuel is prepared to be sprayed into the combustion chamber at the correct time in the injector. The interaction of the measurement valve with nozzle is critical to the completion of discharge from nozzle inlet to nozzle holes of the fuel.(Mollenhauer, Klaus and Tschoeke, Helmut, 2010)

In simple terms, the fuel injection system is shown in Figure 2.8 below. In general, the fuel tank is positioned below the pump and injector level in fuel systems. On the other hand, the lifting pump provides constant pressure to the injector pump for fuel feeding at approximately 0.75 bar. The pressure adjustment valve in the fuel filter prevents the air and fuel bleeding that may occur in the fuel system. Air in the system can cause incorrect measurement of the amount of fuel to be delivered from the injection pump to the injector. More importantly, the narrow operating tolerances in pumps and injectors require the purification of fuel from all materials that may damage the system. The injection pump has a governor to control the speed of the engine. This part allows the engine to operate at the correct speed when it is in idle or under load conditions. (Stone, Richard, 1992)

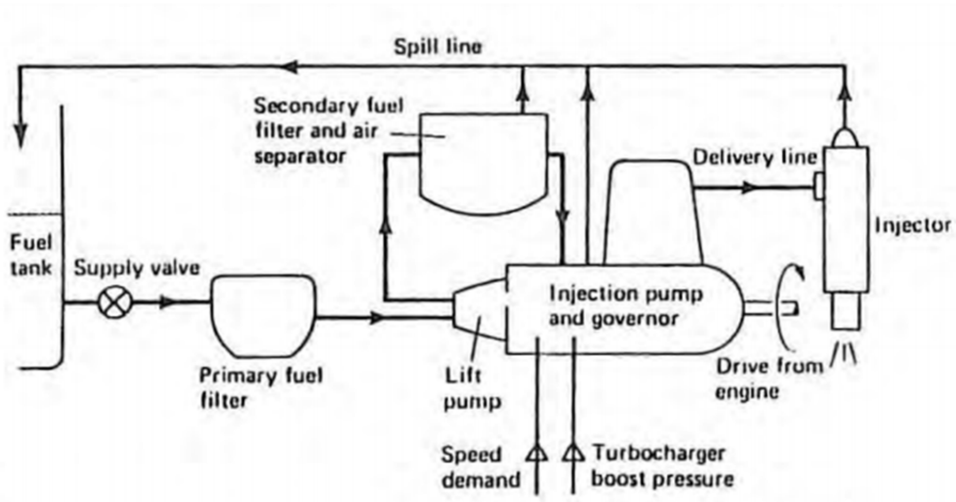

Figure 2.8. Fuel Injection System for A Compression Ignition Engine (Stone, Richard, 1992)

Mechanically operated governors are widely used because of their durable and easy serviceability. It is especially preferred in off-road vehicles. Basically, governors show inline pump characteristics. The main point of the closed circuit feature in the governors is the interaction of a controlled variable with an active variable. Simply put, the amount of fuel required to be injected with the pump setting is control. In a stable situation, the speed increases if the amount of injected fuel is increased. Otherwise, the centrifugal force that affects the controller adjusts the amount of the rack travel by increasing and decreasing. Thus, closed circuit control occurs. The main task of the governor is to limit the maximum permissible speed to which the engine can operate to ensure that the diesel engine is not damaged and functioning efficiently. If the governor will briefly touched on other tasks; ensure the engine start fuel quantity, make the idle speed adjustment, maintain the specific engine speed under different load and conditions, provide torque control.

In diesel engines, without changing the position of the gas pedal, when the engine load is reduced, the speed held within a certain range can only increase at the rate determined by the engine manufacturer. The speed control on the engine is directly related to the load. In other words, the speed varies as the engine load changes. The response of the motor is known as proportional behaviour or proportional degree. Proportional behaviour is defined as the difference between no load maximum speed and full load maximum speed. (Mollenhauer, Klaus and Tschoeke, Helmut, 2010)

Increased demand due to the expected efficiency of the fuel system has provided continuous improvement in the fuel pump. Therefore, many systems have been developed and different methods have emerged in this regard. The main fuel pump systems used today are;

- In line fuel pump with mechanical governor or Electronic Diesel Control with timing device if it is necessary
- Control-sleeve in-line fuel-injection pump, with Electronic Diesel Control and infinitely variable start of delivery (without attached timing device)
- Single-plunger fuel-injection pump
- Distributor fuel-injection pump with mechanical (flyweight) governor or Electronic Diesel Control. With integral timing device
- Radial-piston distributor injection pump
- Common Rail accumulator injection system
- Unit-injector system
- Unit-pump system

One of the important points in the efficient operation of the fuel system is the configuration of the fuel lines. High pressure fuel must be provided and the fuel must be free from air bubbles. Under normal conditions, the difference in height between the fuel tank and fuel injection system elements in passenger cars and light commercial vehicles is negligible. Moreover, in such vehicles, fuel lines are not too long and have the necessary internal diameter. Ultimately, feed pump draw fuel from within the fuel tank and the injection pump has enough power to create pressure.

In the installation phase of the fuel injection system, if the fuel lines are too long or the height between the fuel tank and the injection pump is too high, a pre-feed pump should be added to the system. In this way, the resistance in fuel lines and fuel filters can be overcome. Gravity feed tanks are generally used in stationary engines.

Fuel tanks must not be corrosion and must be produced from materials that do not react with fuel. In addition, even at pressures up to twice the working pressure should not allow leakage. Sufficient openings or safety valves must be in the system for possible high pressure situations. No fuel leaks must be observed in any of the refill caps or similar fuel system elements. This applies to all operating conditions of the vehicle (mechanical shocks, turning, rolling or inclined terrain). In the event of an accident, the engine and the fuel tank must be far enough away from the fire hazard. In addition, there are regulations for the protection of the fuel tank to ensure driver and passenger safety in vehicles.

In addition to steel pipes on fuel lines, steel braided flexible fuel lines produced from non-combustible material can be used for the low pressure fuel line. These fuel lines must be mounted in such a way that no mechanical damage can be done, and in the event of a fuel leak or evaporation on the lines, the fuel must absolutely not accumulate and be ignited.

Fuel injection pumps and injectors are manufactured with a sensitivity of a few thousandth of a millimeter. Therefore, pollution and insufficient filtering in the fuel system can cause problems and damage to the pump, valve and injector. The filter is critically important in ensuring the cleanliness of the system for trouble-free operation and long service life. Another problem is that fuel can contain water. If water enters the injection pump, corrosion can cause damage. Herewith fuel pumps must be installed with a fuel filter that can discharge water at regular intervals. Due to the increasing demand, fuel filter systems are developing every day.(Tschöke,H.,1999)

3. LITERATURE REVIEW

In recent years, fossil fuels have entered the process of depletion because of the increasing environmental damage, scientists have conducted many research studies to reduce fuel consumption and prevent environmental damage. Different methods used in these studies are based on efficiency. In this context, progress has been made on issues such as route arrangements and efficient driving activities.

Ng et al., (2016) studied the interaction between fuel consumption and productivity in a hydraulic excavator. In this context, it provides operators with information on obtaining the best productivity for fuel consumption in hydraulic excavator. The reason for doing this work on excavator, which is one of the most preferred machines in the construction sector, is the ease of use of excavator, versatility and high efficiency. The study was aimed at verifying hypotheses and obtaining measurable evidence with experiments at the point of reducing environmental damage of construction machines. In this study, two variables were determined as engine speed and cutting depth in order to examine the effect of the excavator on productivity and fuel consumption. The results of the study showed that with different engine speed and cutting depth selections, productivity increased by 30%, emissions decreased by 24%, and as a result, 62% more work was done for each litre of fuel every hour. As a result of the experiments, accurate determination of bucket cutting depth was observed to be of critical importance for reduction in emissions and productivity. As a result of the research, the operator's choice of appropriate engine speed and bucket cutting depth is recommended to be considered at the point of reduction of emissions, reduction of fuel consumption, long operation life, and reduction of costs.

Bedotti et al., (2017) investigated the subject of mathematical tool energy saving with load system for hydraulic excavator. A large energy survey was carried out to determine the energy distribution accurately. In order to reduce losses in the system, to save energy from the main components of the machine and to increase fuel savings, a second feeding pump was added and examined in detail. Energy analysis was obtained as a result of the digging cycle according to the Japanese JCMAS standard. In addition, the standard ignores the relationship of excavator with soil or material. In addition, the use of two Load-Sense pumps instead of the hydraulic system's local pressure compensators, and the adjustment of the pump to reduce the loss of the load-sense system are given information. For this reason, the system inputs and outputs need to be hybridized, gravitational potential and kinetic energy to gain energy is utilized. For hydraulic excavators, energy saving solutions obtained according to the analysis performed on the mathematical model were determined and energy diagrams and energy saving results were presented for each solution. The application of load sense systems to excavator and the energy savings obtained were analysed in detail and these energy analyses were evaluated in order to increase machine efficiency. As a result, the researched solutions have led to the emergence of new concepts. The numerical values obtained indicate that 15% fuel savings in the digging cycle.

Rangel et al., (2017) studied the impact of eco-driving training on fuel consumption in three basic conditions in their study. These conditions are in order as follows; heavy and medium segment truck fleets, long distance freight transport, Latin America region. By supporting the effects of variables on fuel consumption with the analysis, the importance of eco driving has been presented by comparing ex ante and ex post data. In the study, operational variables were grouped under driving errors, driver behaviour, vehicle characteristics, driver profile and travel conditions. Again, the application was carried out in a large cargo fleet in Colombia, where roads are inclined and have an active role in fuel consumption. Fleet consisting of 18 trucks are equipped with state-of-the-art real-time data logger systems and data was recorded. According to these records for four months have travelled around 300000 km, carried 10000 tons of cargo and 517 trips have been made. The results of the data were analysed and the values of the fuel consumed at 100 km per ton were measured. The results were analysed and presented according to the different logistic performance parameters. In eco driving training, drivers were introduced to eco driving methods, starting with the basic features of internal combustion engines, and practical applications were made. after eco driving training, fuel consumption decreased by 6.8% and 5.5%. Driver experiences, driver errors, average speed values, weight capacity ratios were determined to significantly affect fuel consumption, along with other variables. Errors, especially driver-induced acceleration, hard braking and high-speed driving, have been reduced by 96% after training.

Zarotti et al.,(2009) in order to evaluate the performance of an excavator, a standard procedure is based on four main operating conditions, such as trench digging, straight travelling, soiling and low idling standby, while some applications and methods were applied for trench digging, which is considered the most important condition in their study. In the first study, hydraulic system pressures and flows were obtained during the cycle load map and operational operation (arm retraction, bucket close, boom up, upper structure swing left, bucket dump, upper structure swing right, and arm extension). In the next stage, the integration of hydraulic power values for each cycle and for total cycle related to hydraulic system operation was calculated in order to obtain the machine energy usage characteristics. At the other stage, the energy utilization characteristics of the same machine are compared with the values obtained by simulations and the values obtained during the actual digging. This part of the study is important to see the effects of external load. On the other hand, it allows to compare the energy usage characteristics of different machines to the same simulated digging. This approach can show the effects of different types of hydraulic systems on the machine.

In Jansen (2012) study, the effect of driving technique on fuel consumption is investigated when steady driving or cruising is used with a parallel hybrid vehicle's burn or coast driving technique. The researcher who worked on a hybrid passenger car tried to find the fuel saving potential in the burn and coast driving technique using the longitudinal vehicle dynamics model. A model-in-the-loop has been used to provide more accurate data about the vehicle's fuel saving potential in the burn and coast drive and to simulate a saw-tooth speed and steady speed conditions. Optimisation of the saw tooth acceleration phase has been performed to minimize fuel consumption of the burn and coast driving technique. According to the study, when the car is used with a average speed of 62 km/h and saw tooth speed profile, fuel consumption dropped by 31%. In addition to the driving model, the automatic transmission control model used in the car has an impact on fuel consumption at different speeds. Down shifts and coasting-gear significantly change the fuel saving potential. An ecologic driver assistance system (EDAS) is designed to make it easier for the driver to drive in saw tooth driving mode. The EDAS offers a gas pedal position to the driver during saw tooth acceleration. This recommendation is intended to ensure that the internal combustion engine operates in the most efficient way during the saw tooth acceleration phase.

Carrese et al.,(2013) has examined two bus lines in Rome, fuel consumption and emissions values can be estimated. The results of the study, especially on the sub-urban line, showed a 27% effect on fuel saving of driving behaviour. The study consists of 3 main sections. These are survey, data post process and emulation model. Different drivers have been monitored in survey section for 4 days. Two main research parameters in the data post process: driving behaviour and slope / load factor impacts on bus fuel consumption / emissions. In the emission model part, it is preferred that the microscopic model is suitable for study from three basic approaches. Although the data obtained from the study are not strong enough to be accepted, it is observed that the slope can double fuel consumption and the load factor affects fuel consumption between 7% and 26%. In addition to fuel consumption, when the emission levels are examined, it is observed that Co and NO_x levels are low in the drive using the average speed range of 50-60 km/h. This speed range is the minimum in terms of emission values. In addition, the number of stop&go and acceleration stage have a significant impact on emissions and fuel consumption, so the standard deviation at speed should be taken into account.

Cavallaro et al., (2017) examined the effects of eco-driving and found some evidence. The data obtained during the study was collected by a program that records real-time data developed by an institution. The study was conducted in an eco-driving area in Jiangsu province of China. 15 heavy duty and 10 light commercial vehicles were monitored for a certain period of time, approximately a distance of 440000 km, and data were recorded during the trip around 5000. The driving and travel data are collected and evaluated through the developed program. Results are obtained by making the necessary comparisons. The program can easily analyse the parameters such as vehicle location, driver performance, CO_2 emission values, fuel costs, driver behaviour, traffic conditions, fuel consumption analyses, route analysis, map and reporting etc. After the training given to the drivers, the comparison between the driving styles was examined, while there was no significant change in fuel consumption in light commercial vehicles, a reduction of around 5.5% in heavy duty vehicles was achieved. It is important that drivers adopt a more efficient and accurate driving style by providing interactive information about braking, acceleration and stopping through the method applied during the research.

Ehsani et al., (2016) studied a mechanical model was applied to examine the effect of different engine models gasoline diesel operating principles, different types of vehicles with different characteristics, different routes, renewable and non-renewable fuels and wind resistance on vehicle fuel consumption and emissions. In this study, the effect of variables such as fuel efficiency, asphalt efficiency, driving behaviour and temperature were investigated. The mechanical modelling was applied based on five variables: gravity, aerodynamic resistance, cornering energy losses, acceleration and rolling resistance. In addition, while investigating three types of tolling systems, the model analysed the parameters in the specific range with the parameters of the mechanical model for the validity of the model.

According to the data obtained from the study, 10% improvement in driving style in cars reduces fuel consumption by about 9%, temperature change increases fuel consumption between 6% and 2%, different asphalt types affect fuel consumption by about 7%, gasoline cars consume approximately 6.8 times more fuel than biodiesel-driven cars. As a result of the study, when fuel consumption values and fuel consumption values are examined, the electronic tolling system provides twice as advantageous in fuel consumption compared to traditional systems.

Wang et al., (2017) has been conducted on the development of fuel consumption model known as bang-bang in heavy duty diesel truck family. Due to the lack of published information for model development, measurements in field tests were used in the research. In the modelling study, while the model is calibrated for each truck, it is compared to two different model estimates and field test results for validation. According to the results of the study, although the empirical fuel consumption values show that the vehicle power has convex functions, it is necessary to have a convex model to provide driving recommendations for the system. The convex model is closer to the other two models to predict consistent fuel consumption values with field tests. According to the results, the minimum fuel consumption values for all vehicles are between 32 and 52 km/h, with 0% to 8% incline levels, while in addition, the vehicle moves in negative directions due to load and incline levels, leading to lower driving speeds with higher incline levels and heavier vehicles. In addition, the model makes consistent CO_2 estimates with field tests. In this study, it is recommended that the fuel values of heavy duty diesel trucks be reported and collected to environmental protection organizations in order to be the source of the calibration studies to be carried out in the future. Fuel consumption values may vary for a variety of vehicles in the same class. Therefore, models based on class-specific fuel efficiency data may fail to determine the fuel consumption values of each truck model.

Zhou et al., (2016) examined whether advanced fuel consumption models are suitable for eco-driving and eco-routing. In this scope, they conducted a detailed study of the factors effecting fuel consumption and fuel consumption models. In this study, the factors affecting fuel consumption were classified as traffic related, travel related, vehicle related, roadway related, driver related, weather related. However, fuel consumption models developed in the millennium have been classified and examined. The models are classified as white-model, grey-model, black-motor, black-model and black-vehicle. The advantages and disadvantages of these models have been demonstrated. In addition, the white, black and grey box fuel consumption models were compared according to different parameters. The data revealed by the study is a guide for later use in the studies.

Duarte et al., (2016) presents fuel consumption and emissions rates between New European Driving Cycle and Worldwide Harmonized Light-Duty test procedures, comparing NO_x, HC and CO_2 values to real-working condition data. Therefore, in real driving conditions, gasoline, diesel, parallel hybrid and full hybrid vehicles were equipped with mobile emission measurement systems and monitored for a certain period. Vehicle-Specific Power methodology on-road data were analysed and observed for both test procedures. According to the results obtained from the test vehicles, the estimated fuel consumption and emissions were measured as high as 23.9 + - 16.8% and 25.5 + - 16.9% respectively, according to the New European Driving Cycle certificate datasheet. On the other hand, when the HC and NO_x values were examined, there were lower predicted values for gasoline engines and hybrid vehicles than for certification. In diesel engines, HC and NO_x emissions predict much higher than the certificate. In the same 16 vehicles, the driving cycles were studied for both test procedures, based on road data estimations, fuel consumption and emissions values were observed. The study showed that the procedures differed considerably due to differences in driving conditions such as average speed, power demand and idle time. At the end of the study, expectations were set by specifying the revisions required to approach the test procedures to the actual fuel and emission values. With the revisions to be made in the certification process, the importance of informing the buyers about the fuel consumption and the emission values in the actual working conditions is emphasized.

Larsson et al., (2009) investigated the effect of vehicle acceleration proposals on fuel consumption and analysed the effect of driving patterns in different routes with traffic-related emission changes. Acceleration management gives drivers the advice of the accelerator pedal when they want a series acceleration movement. According to the driving pattern parameters in the data obtained from the acceleration management system installed on four delivery vehicles in a certain region of Switzerland, it was observed that hard acceleration decreased significantly, and drivers were following the recommendations given. While the acceleration management on some of the roads under investigation has decreased the emission values in some roads, it has been observed that the data obtained in general have no significant effect on fuel consumption.

Hellström et al., (2009) has been conducted with the help of gps equipment on a heavy diesel truck, it has the necessary predictions about the way to go and according to this information it is aimed to reduce the travel time and fuel consumption with a dynamic algorithm by adjusting the speed and route. It has been observed that the control algorithm provides correct results under real operating conditions. Compared to the standard cruise controller, the algorithm is fed from the new set points, preventing errors between the model and actual operating conditions and providing an advantage over distortions. To increase the efficiency during the gearbox shifts in the transmission, an algorithm study has been done to decrease the search area based on previously obtained information. Since the resolution time of the algorithm is very short, it allows instant evaluation in working conditions. Significant decreases in fuel consumption have been obtained according to the test work data. On a test route, a 3.5% reduction in fuel consumption was observed, without changing the travel time. In addition, the speed gains before the steep slopes decreased the slippage, the average gear shifts decreased by 42%. It is difficult to find solutions according to the road conditions, but the algorithm, implemented to achieve positive results seem to support the successful outcome considering the impact on fuel consumption is concerned. In the study, it was observed that the algorithm results can be easily detected by the driver.

Trani et al., (2015) a quantitative model study was performed to estimate fuel consumption in pre-construction and soil works based on a detailed load factor parameter in this study, unlike previous studies. Firstly, after determining the fuel consumption issues related to earthworks, the characteristic specifications of the load factors and fuel devices were formed and thus fuel consumption analysis was performed. The fuel consumption analysis was performed by calculating the load factors for the medium sized tracked excavator, vibratory soil compactor and small wheel loader, using the technical datasheet of the manufacturers, data obtained by a specific analytical method and linear regression. The method has been verified by testing at a construction site, and the data obtained at the end of the study presented results to the engineer responsible for the construction site on which the machine is more sustainable. With this system, it can be estimated how much fuel will be consumed for the construction project, and the costs can be calculated and in addition, necessary design changes can be made to reduce fuel consumption.

Lin et al., (2016) an energy regeneration system was investigated on hydraulic hydride excavator in this study. Because of the use of hydraulic accumulator and hydraulic motor generator in the investigated structure, it is ensured that the boom goes down to a low level regardless of the energy gained from regeneration by the hydraulic engine and generator. The control method defined as the accumulator hydraulic motor generator energy regeneration system has been shown in detail and it has been stated that it performs well according to the results. The recovery efficiency of the control method has been determined as 39% according to the data obtained and it has been emphasized that it can be further improved with different control valve options. As a result, they advise that recovery times can be extended by reducing hydraulic engine and generator capacities.

Triantafyllopoulos et al., (2017) the transition of the World Wide Harmonized Light Duty Test Procedure to the New European Driving Cycle procedure was examined to determine the reduction values of CO_2 emissions in accordance with the final procedure and to improve efficiency by revision in various parts of vehicles. For both test procedures, comparisons have been made on issues such as rolling, aerodynamics, driving resistance, and weight reduction. When the powertrain groups are examined, the procedures must be implemented and more comprehensive operating conditions must be addressed in order to reduce the emission levels of engine restrictions. In addition, energy recovery and start stop systems show similar benefits. The total effect of all the technology options in the study was approximately 14% and 13%, respectively, for gasoline and diesel vehicles. According to the data obtained in the actual driving conditions, it is stated that there is a great similarity between the procedure and the values are determined as 13% and 12% respectively. Thus, it can be said that the test procedure is satisfactory in achieving real world efficiency values. Evaluations were made on the expectations of the test procedure for today and the future. The study evaluated to expected fuel consumption by using simulations on actual driving conditions.

Barla et al., (2017) The study examined the impact of eco-driving training on fuel consumption as well as sustainability and heterogeneity. Within the scope of training given to drivers in a specific period, basic driving techniques such as acceleration, deceleration, gear shifts, stable speed, driving according to traffic situation, shortened idling times and vehicle maintenance were informed. The effect of eco-driving techniques on fuel consumption according to the data obtained in the ten-month period of the study was determined by 5% to 3% in urban and highways respectively. Again, the results showed that there was a 5% standard deviation and the response of drivers to eco-driving techniques varied.

However, it is stated that half of the drivers have significantly reduced fuel consumption. According to the results obtained, the decrease in fuel consumption in the first days after the training gradually decreased and became insignificant. In order to get maximum benefit from eco-driving techniques, drivers need to apply these techniques continuously. This means repeated training at a certain interval. However, it is stated that the average driver saves 60 dollars per year considering the fuel prices in the city where the test was carried out according to the data obtained. Even these values show that a large amount of savings can be made only by education without any investment.

Wang et al., (2009) when testing hybrid operating performances of powertrain equipment, it compares the main performance values in conventional, parallel and series applications. For the study, the excavator with low fuel consumption efficiency and high emission values was preferred and analysis was made on a compact excavator in the 5-ton segment. The data of the conventional excavator used in the study were obtained from real working conditions, while modelling for obtaining data in hybrid applications was obtained from simulations. The load factor values used in the modelling are also integrated into the modelling by obtaining the working conditions. In hybrid application modelling, a reliable approach model has been established. The results of the study show that hybrid applications have lower fuel consumption compared to other applications, and parallel and serial hybrid applications have reduced fuel consumption by working efficiently in certain conditions of use. Considering the costs and results of the analysis study, the most efficient application for hybrid excavators should be parallel powertrain.

Zhang et al., (2016) an empirical modelling study was carried out to estimate fuel consumption and emissions for light duty passenger vehicles by selecting a region with traffic and population density. Vehicle weight and engine displacement are taken into account simulations. The model was set up to make predictions based on the average speed, load mass and usage of air conditioning devices. Moreover, it can be used to calculate total fuel consumption and emissions for registered vehicles. Even though vehicles with low fuel consumption and emission values are preferred in the tested area, increasing vehicle quantity has made it difficult to reach the desired conclusion at the point of reducing fuel consumption and emission values. Therefore, fuel consumption and emissions increased by 55% compared to previous years. The estimations of the study were compared with the fuel sales figures at certain time intervals and it was observed that the estimates were compatible. According to the data obtained from the study, traffic conditions significantly increased fuel consumption and emission values depending on time and location. As a result of the evaluations, it is recommended to develop public transport by emphasizing the necessity of effective measures in the test zone where fuel consumption and emission values are critical to be reduced. In addition, it is emphasized that incentives for the use of hybrid and electric vehicles will be in place.

Liu et al., (2016) collected and analysed information on fuel consumption and emissions of alternative fuel vehicles in real-life driving conditions and performed performance tests in study. A study on the driving cycle, which is critical to fuel consumption and emissions, has been carried out and data that will be the basis for the design of the driving cycle has been obtained by creating a comprehensive database. In order to create the driving cycles, the input information is considered as flexible as possible, taking into account the different needs. The study compared the performance of different fuel-powered vehicles in real driving conditions before the vehicle-specific privatization of driving cycles. The values obtained in real driving conditions and the values generated in standard driving cycles vary. This is why data based on real driving experience can lead drivers who are sensitive about fuel consumption and who plan to take a car to alternative fuel-powered vehicles in their choice. Analysing data collected from many different drivers and vehicles, this study extracts information on mini trips with 23 driving performance parameters. These data are presented by grouping with different techniques. All this data collection, analysis and grouping work is the basis for the design of highly efficient driving cycles. In addition to the data previously available during the creation of the driving cycle algorithms, variables such as driver age, gender, income, travel time and distance are synthesized to create the driving cycle. In this way, with these drive-specific driving cycles, vehicle-specific power equations can be found, and with mechanical experience or simulations, fuel consumption can be estimated.

Ericsson et al., (2006) the study estimates were made about the potential to reduce fuel consumption, and total fuel consumption was reduced by using a navigation system to reduce emissions. The navigation system is also optimising by providing information about the traffic situation on the roads. The analysis is based on a large database of traffic driving patterns. Approximately 15,000 cases were analysed and estimates were made for three types of vehicles, classified transport network, time intervals when traffic was highest, and two mechanical emissions models. The average fuel consumption was calculated considering the traffic flow for the hours where traffic was highest and low on the classified roads. Some test data have been extracted for more accurate results about the navigation system. In addition, the route has been determined for the shortest time and distance to the destination using software applications, thus the most economical route has been determined. In order to provide more potential benefits, measurements were made by means of equipped with probe vehicles to provide instant data on the traffic situation. When data collected were analysed, 46% of the trips made by the drivers were not the shortest route selection. This means that fuel consumption is too much to be required. If the trips are optimised by determining the navigation system, it is estimated that fuel saving can be achieved by around 8%. This corresponds to 4% fuel savings for all journeys in the city where the test is being carried out. As a result of the study, it was understood that the values of the potential fuel consumption could decrease significantly with the knowledge of the instantaneous traffic condition especially in areas where traffic is obstructed.

Tavares et al., (2008) the aim of the study is to develop a model for route optimization in order to improve the fuel consumption of waste collection vehicles. The model was developed using geographic location information systems and extensions, and its effects on travel distance and cost were investigated using different collection and transportation methods. The application was studied in two stages as collecting and transporting waste. The differences between the 2D and 3D optimizations on the route were observed. The basic factor in the difference in fuel consumption is the slope factor of the way to go in the optimizations made with the 3D model. What's more, the test shows that 8% of fuel is saved even at a distance of about 2% longer. Regardless of the optimization model, switching from 2D to 3D increases fuel consumption by 80% to 57%. In addition, compared to the optimizations made according to the lowest fuel consumption instead of the optimization made according to the shortest distance, 12% fuel consumption decreases. When the data obtained from the study is evaluated collectively, it is more efficient to optimise the lowest fuel consumption rather than optimising the shortest distance and shortest time. It is also recommended to use 3D models instead of 2D models.

Niraula et al., (2018) investigated the weight effects of direct driven hydraulic systems on the mini excavator. In the scope of the study, the effects of zonal and non-central hydraulic applications on energy in non-road machines and industrial applications were investigated. Direct-driven hydraulic systems combine electrical and hydraulic systems with more compact equipment than conventional hydraulic systems. At this point, the critical leakages and flexible pipes are reduced and the system is dominated over the pump instead of the control valve ensures increased application efficiency. With structural analysis studies, a model has been established to estimate the energy distribution of direct driven hydraulic systems in various operating cycles. The finite element analysis showed that the extra weight of the direct drive hydraulic system did not affect the structure of the mini excavator. According to the simulation results, it was observed that the direct-driven hydraulic system component weights increase the machine's energy consumption by 15%. Although the regeneration energy obtained from the system is 20% more, the increase in overall energy consumption is 12%.

Tong et al., (2000) to perform emission and fuel consumption tests, four vehicles were connected to measurement equipment, instantaneous emission values from vehicle exhaust pipes were collected as data, resulting data were analysed microscopically and macroscopically for fuel consumption and emission values. The average factors and indices for the vehicle were calculated over the data. The highest emissions were observed on a double-decker bus. The indices are derived for acceleration, cruise, deceleration and idle driving modes considering modal emissions, fuel consumption rates and impact factors. Compared to driving modes, fixed speed driving modes, such as cruise and idling, produce less emissions than driving modes, such as acceleration and deceleration. According to the results of the micro analysis, instantaneous vehicle speed has the greatest effect on distance-based emissions and fuel consumption, while time-based emissions and fuel consumption rates are followed. Emissions and fuel consumption rates, impact factors, instantaneous speed indices are at the same level as laboratory tests. in addition, the results of the micro analysis indicate that low speed ranges have the highest emission values. In addition, modal analysis shows that the emission values in the idling are high. As clearly seen, idling and low speed has effect on emission values. The missing part of the study was the use of a single test vehicle for each segment, while the study examined the basic behaviours in terms of emissions and fuel consumption. The results show that emission measurements can be performed while driving. Examining more vehicles is important in achieving the right results.

When all these studies are examined, it is observed that different ways of reducing fuel consumption are carried out. In this thesis, fuel consumption values were determined by performing field tests on hydraulic compact excavator. Hydraulic pressure, hydraulic flow, instantaneous fuel consumption, average fuel consumption and compact excavator cycle time values obtained during the test were analyzed. As a result of these analyses, efficient working rpm were obtained.

4. MATERIAL AND METHOD

The main objective of this thesis is to ensure the efficiency of the compact excavator, which is widely used, and to reduce fuel consumption and emissions. For this purpose, instead of modelling and programming, optimum fuel consumption values were obtained by searching hydraulic system, machine speed (cycle time) and fuel consumption values in real working conditions. To determine working modes for efficient use of the compact excavator with minimum fuel consumption and emission values.

4.1. Material

4.1.1. Test Equipments

Technological measurement and monitoring devices were preferred in order to achieve more accurate results in the study. Before the trial, the devices were assembled in suitable positions and their functionality was checked.

4.1.1.1. Hydraulic Flowmeter

Hydraulic flow meters have a simple structure, high accuracy, good repetitiveness, fast response time and easy maintenance. It is widely used for liquids which are not corrosive to stainless steel, and do not have fibre or particles. The liquid must also have a kinematic viscosity less than 50×10^{-6} m^2/s.

Features:

- High accuracy: ±1%, ±0.5%, ±0.2%
- Good repetitiveness: 0.05% ~ 0.2%
- Output of pulse frequency signal, suitable for totalizer and connection with PC; no zero shift and interference resistant
- High frequency signal (3~4 kHz), strong signal resolution
- Turndown: 1:20, 1:10
- Compact structure & easy maintenance (AGE,2019)

Table 4.1. Basic Parameters of Liquid Flow meter

Instrument Diameter (mm) & Connection	4, 6, 10, 15, 20, 25, 32, 40 thread connection (15, 20, 25, 32, 40) 50, 65, 80, 100, 125, 150, 200 flange connection
Accuracy	±1%, ±0.5%, ±0.2% (special order)
Turndown	:10, 1:15; 1:20
1 Instrument	Material SS304, SS316 (L)
Medium Temperature	-20 to +120 Degree C
Ambient Conditions	-10 to 55 C, Temperature relative humidity 5% to 90%, atmospheric pressure 86 to 106 KPa
Output Signal Sensor	pulse frequency signal, low level≤0.8V,high level≥8V transmitter: two wire, 4-20 mA DC current signal
Power Supply	Sensor: +12V DC, +24V DC (optional) Transmitter: +24V DC Local indication type: built-in 3V lithium cell or +24VDC external
Signal Transmission	Wire STVPV3×0.3 (3 wire), 2×0.3 (2 wire) Transmission Distance No more than 1000 m
Signal Line Interface	Basic type: Hausman connector or 3-core wire; Explosion-proof type: M20 × 1.5 (F)
Explosion Proof	Basic type: non-explosion proof; explosion proof type: ExdIIBT6
Enclosure Protection	IP65

This product itself has no local indication function, only remote transmission of flow signal. Flow signal can be divided to pulse signal or current signal (4-20mA); low price, high integration level, small volume, especially suitable for using together with secondary indicator, PLC, DCS, etc. computer control system. (AGE,2019)

Figure 4.1. Hydraulic Flow Meter Examples from Age Liquid Flow Meter (AGE,2019)

4.1.1.2. Speedometer

The Remote Optical Laser Sensor Monarch ROLS24-W has a visible red laser light source and green LED on-target indicator. The class 2 laser source acts as the aiming device during setup and can accurately measure speeds from 1-250,000 RPM from a distance of up to 25 feet with a maximum offset angle of 60 degrees from the rotating object. The sensor is housed in a threaded 303 stainless steel tube and supplied with a 90-degree mounting bracket, jam nuts and an eight foot shielded cable. (MONARCH, 2019)

Specifications:

Speed Range:	1-250,000 RPM	
Illumination:	Visible Red Laser, Class 2	
Laser Specifications:	Classification: Class 2 (per IEC 60825-1:2014) This product complies with IEC60825-1 Ed. 3 and 21 CFR 1040.10 and 1040.11 except for deviations pursuant to Laser Notice No. 50 of June 2007	
	Maximum Laser Output:	1mW
	Pulse Duration:	Continuous
	Laser Wavelength:	650 nm
	Beam Divergence:	<1.5 mrad
	Beam Diameter:	4 x 7 mm typical at 2 meters
	Laser Diode Life:	8,000 operating hours MTBF
On-Target Indicator:	Green LED on wire end cap	
Operating Range:	up to 25 feet [7.6 m] and 60 degrees offset from target	
Power Requirement:	24 Vdc ±10%, 0.4W max	
Output:	Open Collector with internal pull up resistor to ~20V Positive pulse when target present – Output Voltage=Supply Voltage Optional – TTL pulse, Negative pulse	

Operating Temp.:	14 °F to 158° F [-10 °C to 70° C]
Humidity:	Maximum relative humidity 80% for temperature up to 88 °F [31 °C] decreasing linearly to 50% relative humidity at 104 °F [40 °C]
Connection:	Tinned wires
Cable Length:	8 feet [2.4 m]
Material:	303 Stainless Steel supplied with two M18 Jam Nuts and Mounting Bracket
Lens:	Acrylic Plastic
Dimensions:	Threaded Tube 3.12 in x 0.71 in diameter [M18 x 1.5 x 79.4 mm

Figure 4.2. Speedometer Examples from Monarch ROLS24-W (MONARCH, 2019)

4.1.1.3. Industrial Pressure Transmitter

The economic pressure transmitter ECT 8472 is based on the tried and true ECT line of transmitters. The wide media temperature range from -25 to 125°C in combination with a comprehensive set of features and options makes the ECT 8472 pressure transmitter a versatile solution suitable for most industrial applications. (TRAFAG,2019)

Specifications:

Accuracy:	TEB typ. @ -25 ... +85°	± 3.0 % FS typ.
	Accuracy @ 25°C typ.	± 0.5 % FS typ.
	NLH @ 25°C (BSL) typ.	± 0.2 % FS typ.
	TC zero point and span typ.	± 0.03 % FS/K typ.
	Long term stability 1 year typ.	± 0.3 % FS typ.

Electrical Data:	Output / supply voltage:	
		4 ... 20 mA: 24 (9 ... 30) VDC
		0 ... 5 VDC: 24 (10 ... 30) VDC
		1 ... 6 VDC: 24 (10 ... 30) VDC
		0 ... 10 VDC: 24 (15 ... 30) VDC
		0.5 ... 4.5 VDC ratiom.
	Rise time:	Typ. 1 ms / 10 ... 90 % nominal pressure
	Switch-on-delay:	Max. 1.5 s

Inverse-polarity protection,
short-circuit strength
@ 25°C during 5 min. : 4 ... 20 mA: to Us = 30 VDC
0 ... 10 VDC, 0 ... 5 VDC,
1 ... 6 VDC: to Us = 30 VDC
0.5 ... 4.5 VDC ratiometric:
to Us = 5.25 VDC

Environmental Conditions:

	Media temperature:	-25°C ... +125°C
		400 bar/5000 psi: -10°C...+125°C
	Ambient temperature:	-25°C ... +125°C
		Cable PVC 22: -5°C ... +60°C
		Cable PUR 24: -20°C ... +70°C
		Cable Raychem 08: -20°C ... +100°C
	Protection:	IP65, IP67, IP68
	Humidity:	Max. 95 % relative
	Vibration:	4 g (10...2000 Hz)
	Shock:	50 g / 8 ms
EMC Protection:	Emission:	EN/IEC 61000-6-3
	Immunity:	EN/IEC 61000-6-2

Mechanical Data:

Sensor:	Ceramic, $Al2O3$ (96 %)
Pressure connection:	57/87: 1.4305 (AISI303
	59/89:1.4404/1.4435 (AISI316L)
	52/82: 1.4462 (AISI318LN)
	53/83: Titanium Grade 5
Housing:	57/87: 1.4305 (AISI303
	59/89: 1.4404/1.4435 (AISI316L)
	52/82: 1.4462 (AISI318LN)
	53/83: Titanium Grade 5
Sealing:	FKM 70 Sh, CR, EPDM
Male electrical plug:	See ordering information
Weight:	~ 110 g
Mounting torque:	15 ... 20 Nm

Figure 4.3. Industrial Pressure Transmitter Examples from Trafag

4.1.1.4. Fuel Consumption Measurement Device

Fuel flow meter AIC – 884 / 888 diesel consumption flow meter for live testing while driving for engines up to 515 KW (700 HP). Instructor flow meter is the instrument for live testing on board vehicle. Made for pulsating liquids, the true consumption of the vehicle engine is measured by switching the return flow from the tank, directly to the fuel supply line. Flow meter device can be used in medium and wide trucks, buses, construction machines, tractors etc. vehicles. Media that can be measured diesel, bio-fuel and liquid gas. The measuring system consist of one AIC-888 INSTRUCTOR flowmeter, one board computer, BC 3034, signal connection cable, set of installation fittings.

Each unit is produced as one module in the interests of simple installation. All holders and housing parts are made of stainless steel or anodized aluminium. The consumption of fuel for engines can be measured by 2 ways: Direct (means that there is no fuel returning to the tank, the return flow is reinjected in the fuel circulation flow of the injection circuit Differential (means that the supply and return flow are subtracted. The return fuel flow goes back in the tank. AIC SYSTEMS Ltd. has strongly developed the best measuring solution: the DIRECT flow measurement. This solution allows a true measurement of the fuel flow, within a uncertainty better than +/- 1 % (+/- 0.2 % repeatability). The differential fuel flow allows only an accuracy of best 5 % or worse.

The control and pulse technology is based on the latest SMD technology and is moulded to be water tight and vibration resistant (Pat. AIC). This allows high pulse count per flow quantity unit. The AIC-888 INSTRUCTOR is supplied with 804 ppl (pulses per one litre).

The rotary piston technology fits the fuel consumption measuring principle perfectly, a single moving piston oscillates softly in a measuring chamber protected by a thin layer of fuel maintaining the piston self floating. This allows the meter to have the less possible mechanical friction. Under normal working conditions the measuring cell pressure loss is max. 100 mbar. (AIC,2019)

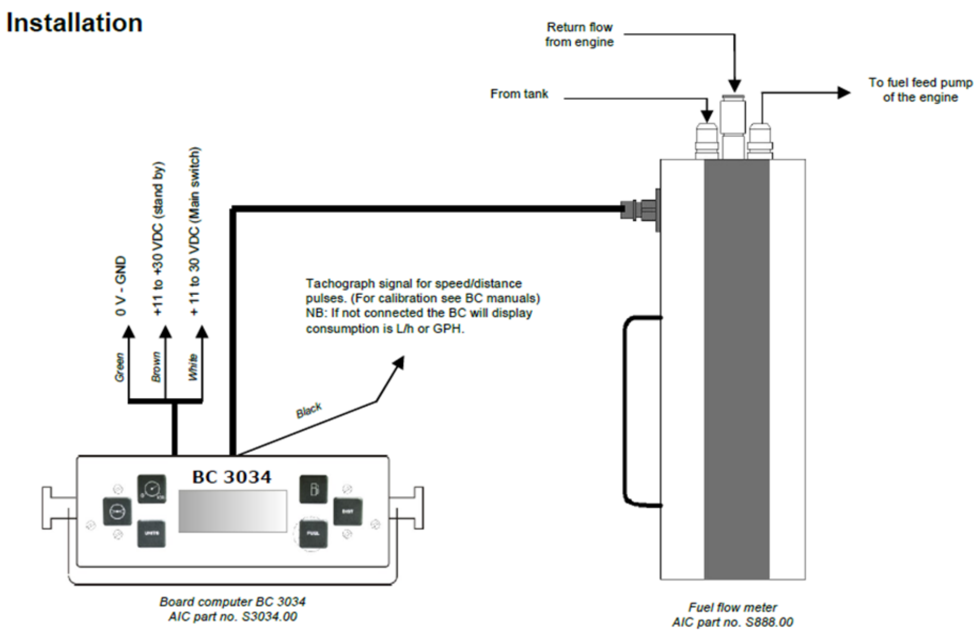

Figure 4.4. Installation of AIC-884/888 Measurement Device

Technical Data of AIC 884/888 INSTRUCTOR:

Mechanical Data:	Dimensions (L x l x h)	290 x 135 x 60 mm 300 x 150 x 70 mm (incl. mounting bracket)
	Weight	3.6 kg 0.2 kg (mounting bracket)
Materials:	Flow meter sensor	Brass, aluminium
	O-ring	Viton®
	Connectors	Steel anodized, Stainless Steel, Brass
	Casing and mounting bracket	Stainless steel and aluminium
	Tubing (internal)	NBR
Flow Meter:		
	Measurement principle	Volumetric, oscillating piston, with microprocessor controlled pulse emitter (Pat. AIC)
	Measuring range	1 to 80 l/h (884) 4 to 200 l/h (888)
	Accuracy	better than 1 % of reading
	Repeatability	better than 0.2 % of reading
	Admissible pressure	- 1 to 3 bar
	Mounting position	indifferent
	Operating temperature	-30 ... 90°C
	Ingress protection	IP 67
Electrical Connection:		
	Power supply	8 - 28 VDC / 30 mA
	Pulse signal	rectangular NPN, open collector, pulse width 0.6 ms
	Pulse rate	2000 ppl (884) 804 ppl (888)

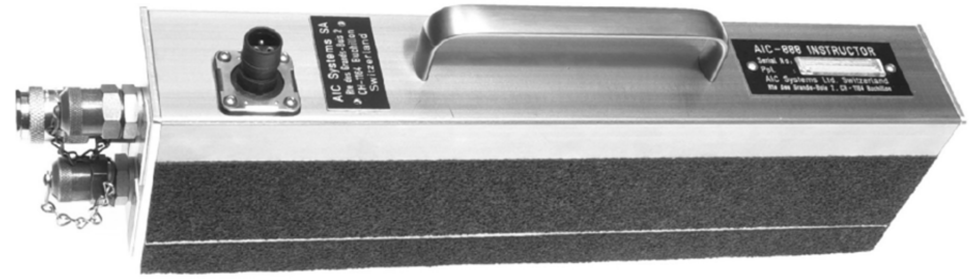

Figure 4.5. Fuel Consumption Measurement Device Examples from Aic

4.1.2. The Test Compact Excavator

Compact excavators are often one of the most widely preferred machinery in agriculture, mining and construction. In addition, it provides important facilities in narrow working areas, in agricultural gardens and in urban construction. Zero tail feature ensures safe and harmless operation. Excavators produced in different segments have pallets and wheels options. For better strength, lifting and balancing, the rear side of the excavator has a component known as the counterweight. Today, although the study of hybrid and electric power generation systems in excavators has increased, internal combustion engines are widely preferred as a source of power for the time being.

All the movements in the excavators are carried out by integrating the power obtained from the engine into the hydraulic system via a pump. The power transmitted to the hydraulic system via the pump enables the machine to be able to travel, turn, levelling, lifting and digging. In order to achieve this, high pressure and flow of hydraulic oil between the pump and hydraulic travel motor, turret motor and motion cylinders are made through high pressure resistant hydraulic hoses. The control of the oil to be transmitted to the hydraulic components is provided by the hydraulic component called the main control valve.

Excavators are basically made up of three parts. These are lower structure, upper structure and attachments group. The upper structure includes internal combustion engine, fuel and oil tanks, operator cabin, electrical components, cooling units, hydraulic main control valve, air filters, exhaust and hydraulic pump. Hydraulic pump provides pressurized oil to the system. The main control valve determines the flow direction and amount. The independent movement of the lower and upper chassis is provided by the turret motor. From the upper chassis to the lower chassis, the hydraulic crossing is provided with the center joint. The lower structure consists of components such as travel motors, pallets, undercarriage parts, dozer blade and bearing ring.

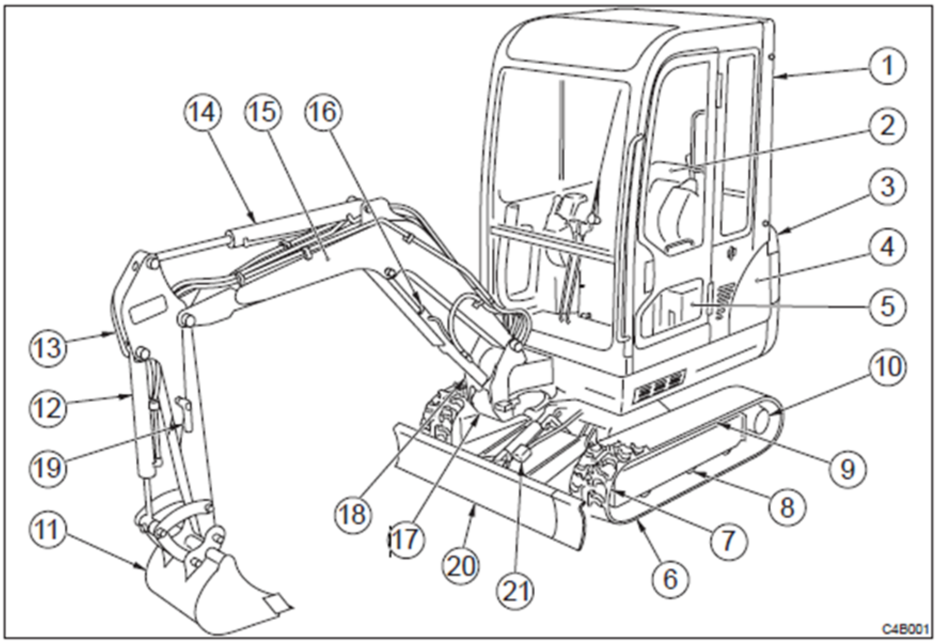

Figure 4.6. Component Visuals of a Typical Compact Excavator (Takeuchi Operator's Manuel,2006)

The front attachment group of excavators is the main part of the work. This section consists of three main metal structures: boom, arm and bucket. Three hydraulic cylinders that allow the movement of these parts are called boom, arm and bucket. In addition, pins are used to ensure that these parts are connected to each other. Boom is the largest part of the attachment group and the movement is achieved by one or two hydraulic cylinders according to the machine segment. The boom, which consists of welded parts, performs the lifting function in the front attachment group. The arm is connected to boom and bucket at two points. The arm provides the back and front movement of the bucket during operation and provides the digging force on the ground. In the final part, bucket performs the function of digging and carrying the soil. All these movements are controlled by the joystick inside the operator cabin. Figure 4.6, Figure 4.7 and Table 4.2, Table 4.3 show the components of a typical compact excavator.

Table 4.2. List of Components a Typical Compact Excavator

Reference No	Description	Reference No	Description
1	Cab	12	Bucket Cylinder
2	Seat	13	Arm
3	Engine Hood	14	Arm Cylinder
4	Fuel Tank	15	Boom
5	Hydraulic Tank	16	Boom Cylinder
6	Crawler Belt	17	Boom Bracket
7	Idler	18	Swing Cylinder
8	Track Roller	19	Aux. Hydr. Line
9	Shoe Slide	20	Dozer Blade
10	Travel Motor	21	Blade Cylinder
11	Bucket		

In this thesis, hydraulic compact excavator with three cylinders, water cooled, four-stroke, atmospheric engine, two variable displacement piston pump and gear pump, maximum hydraulic flow of 94 liters was used. In addition, the excavator has a pilot pump driven directly from the engine to provide the necessary pressure to the pilot line. The working weight of excavator is 3600 kg. Hydraulic working pressure is 250/230 bar. Table 4.4, table 4.5, table 4.6, table 4.7, table 4.8 and table 4.9 also provide the technical specifications of the M38 compact excavator.

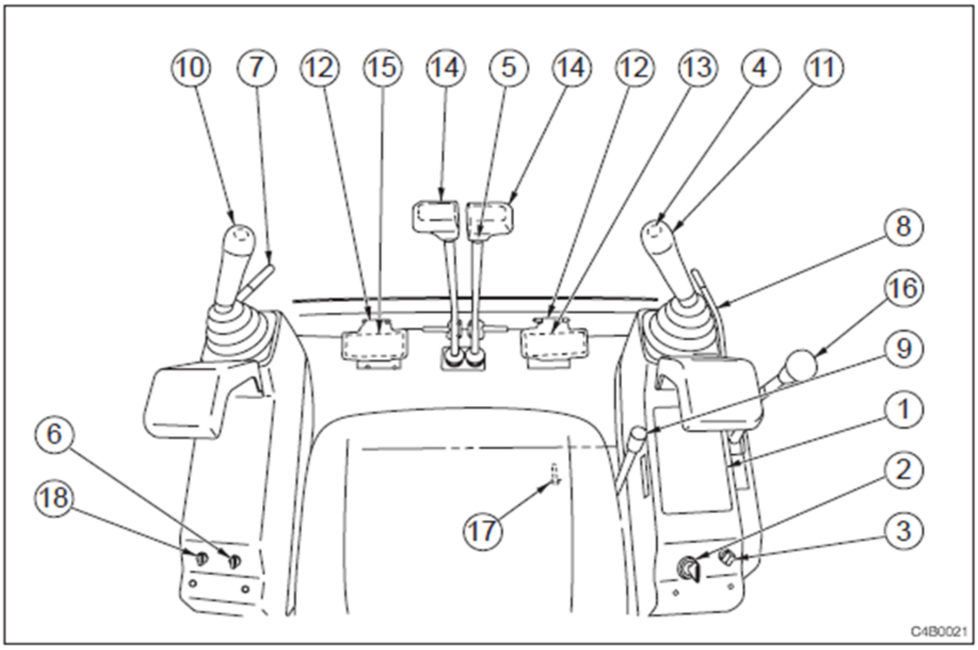

Figure 4.7. Interior Component Visuals of a Typical Compact Excavator (Takeuchi Operator's Manuel,2006)

Table 4.3. List of Interior Components a Typical Compact Excavator

Reference No	Description	Reference No	Description
1	Instrument Panel	10	Left Joystick
2	Starter Switch	11	Right Joystick
3	Light Switch	12	Pedal Lock
4	Horn Switch	13	Boom Swing Pedal
5	Travel speed switch	14	Travel Lever
6	Wiper Switch(cap)	15	Auxiliary Pedal
7	Safety Lock Lever	16	Blade Lever
8	Safety Lock Lever(canopy)	17	Selector Lever
9	Throttle lever	18	Heater Switch

Table 4.4. List of Engine Specification of Test Excavator

Engine Specifications	Description
Brand	Kubota
Model	D1703M
Max Power	27.4 Kw at 2800 rpm
Rated Horse Power	26.5 Kw at 2400 rpm
Max Torque	111.7 Nm at 1700 rpm
Cylinders	3
Displacement	1647
Bore and Stroke	87 x 92.4 mm
Cooling	water
Battery	1-12V – 65 Ah

Table 4.5. List of Hydraulic System of Test Excavator

Hydraulic Specifications	Description
2 Variable Displacement Piston Pumps	34 x 2 Lt / min
Gear Pump	27 Lt / min
Total Delivery	94 Lt / min
Auxiliary flow for P.T.O.	61 Lt / min
Max Working Pressure	250 / 230 bar
Pilot Pressure	30 / 35 bar

Table 4.6. List of Refuelling Capacity of Test Excavator

Refuelling Capacity	Description
Fuel tank	35 liter
Hydraulic Oil Tank	56 liter

Table 4.7. List of Undercarriage Specifications of Test Excavator

Undercarriage Specifications	Description
Track Type and Width	Steel 300 mm
Track Bearing Rollers	4+4 low / 1+1 up
Track Tensioning	Grease
Dozer Blade	310 x 1760 mm

Table 4.8. List of Travel and Brakes Specifications of Test Excavator

Track and Brakes Specifications	Description
Type	Hydrostatic and Planetary Gears
Travel Motor	Orbital
Travel Speed	2.2 / 4.3 Km/h
Max Gradient Capability	100 more than %

Table 4.9. List of Performance Specifications of Test Excavator

Performance Specifications	Description
Operating Weight	3600 Kg
Shipping Weight	3500 Kg
Break Out Force	3100 daN
Digging Force	1950 daN
Specific Ground Pressure	0.328 Kg / cm^2

The fuel system is schematically illustrated in Figure 4.8 in order to make the study of the compact excavator's fuel consumption more understandable. The integration of the fuel system on the vehicle has been made in accordance with the recommendations of the engine manufacturer.

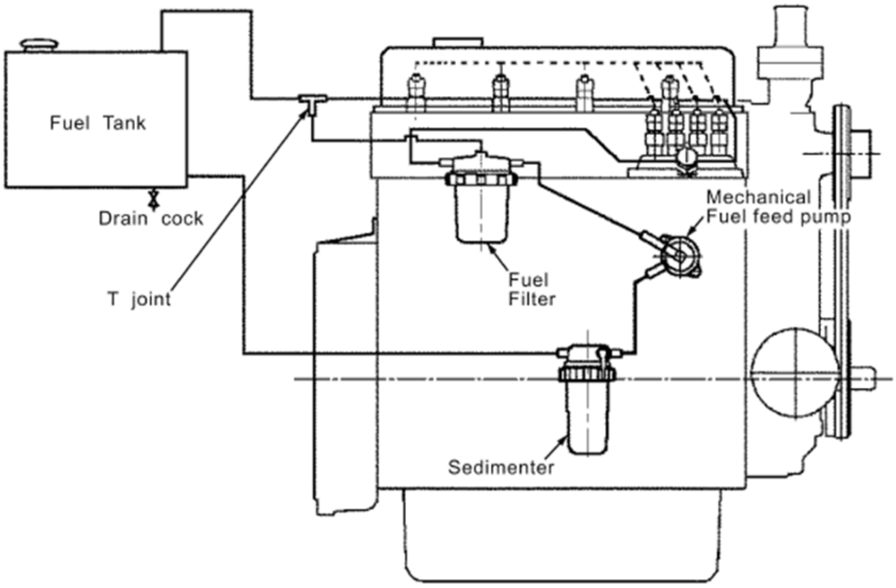

Figure 4.8. Standard Fuel System Application of D1703M(Kubota Application Manuel, 2018)

Double axial piston pump is a variable displacement piston pump which offers two kinds of displacement of an equal capacity by one cylinder block. Since this pump comprises one rotary group, there is only one suction port. But the discharge port is divided into two sections. The third pump or a pilot pump can be connected to the same shaft via coupling. The control method employed is simultaneous tilting angle full-power control. (Messersi, 2013)

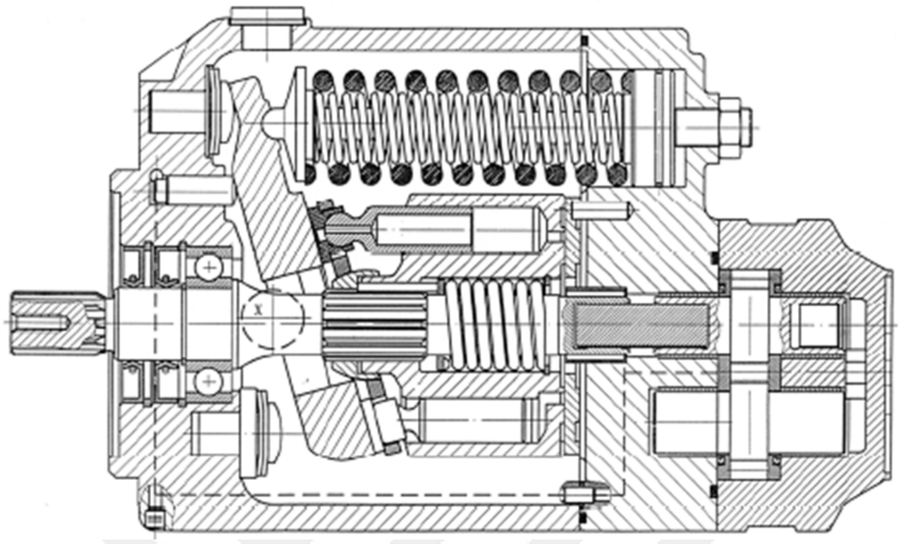

Figure 4.9. Double Axial Piston Pump with Variable Displacement (Messersi Service Handbook, 2013)

Main control valve (MCV) is the other critical component for compact excavator. It acts like a brain in hydraulic system. In neutral position, pump delivery reflows to the tank without pressure. When operating the spool, the connection from the pump to the user opens through fine adjustment edges while central channel is throttled (negative covering). If pump pressure exceeds user pressure, the non-return valve opens and the fluid starts flowing to the user. With an additional spool 3 commutation you obtain a progressive flow deviation from central channel to user channel (progressive adjustment). Spool stroke is divided into three phases: one phase for covering of adjustment edges (neutral position seal) 35%, progressive adjustment range (pressure and delivery) 45%, residual stroke (total opening) 20%. Thanks to the wide progressive adjustment range (45%) it is possible to carefully check the users. (Messersi, 2013)

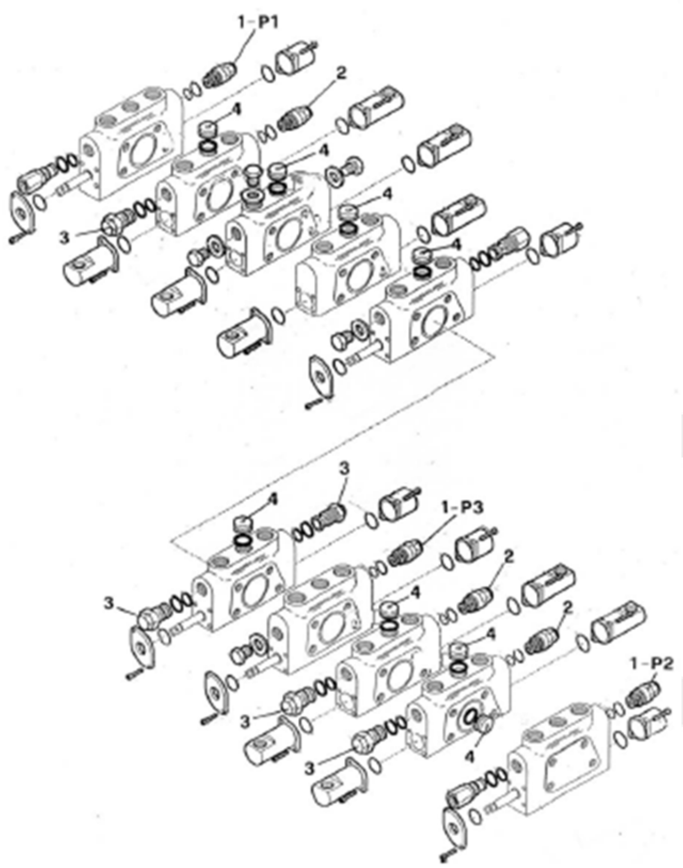

Figure 4.10. Main Control Valve (Messersi Service Handbook, 2013)

4.2. Method

4.2.1. Preparation of Test Compact Excavator

Diesel engine and hydraulic system routine maintenance was carried out. After the maintenance, the machine was operated until the hydraulic operating temperature (60º C) and the system controls were carried out. In this context, the components that will perform the main task during the test are greased at the points specified in Figure 4.11. Greasing process ensures smooth operation of the machine to minimize possible losses. On the other hand, control of the travel system elements from the points specified in figure 4.12 and 4.13 has been carried out and the pallet tension has been brought to the correct level. Maintenance covers are opened, and hydraulic leaks are checked. In addition, the hydraulic system pressures were controlled from the points specified in Figure 4.14 and Figure 4.15 and necessary adjustments were made.

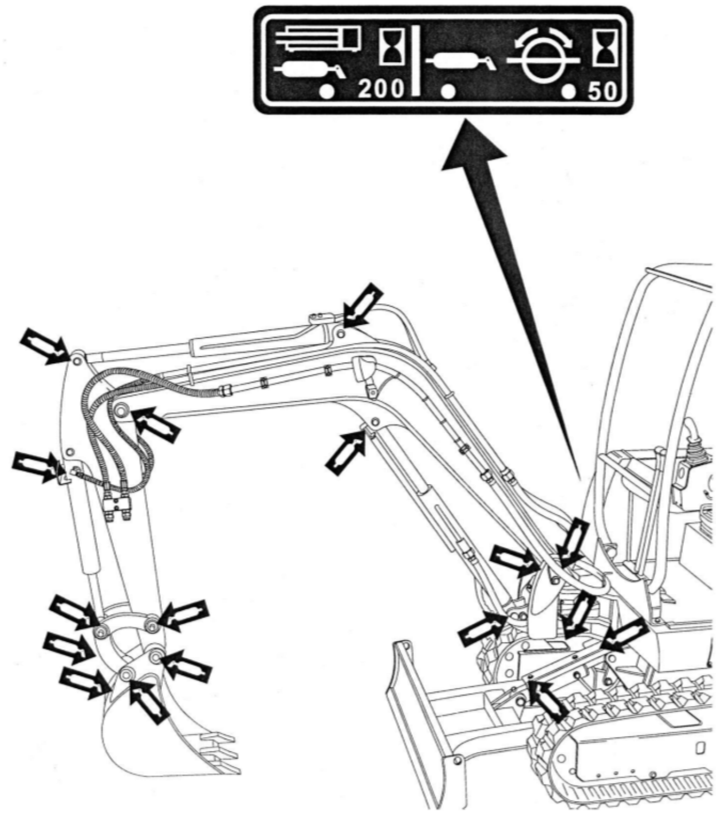

Figure 4.11. Greasing Points of Test Compact Excavator (Mst User Maintenance Guide, 2016)

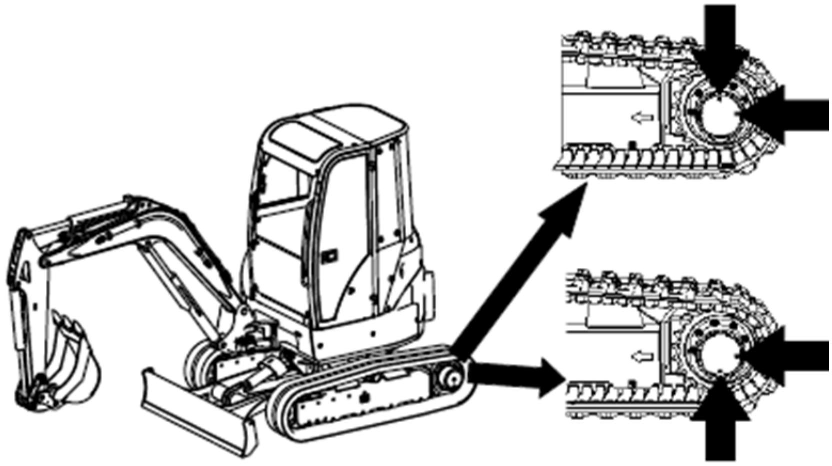

Figure 4.12. Check Points of Test Compact Excavator Travel System (Mst User Maintenance Guide,2016)

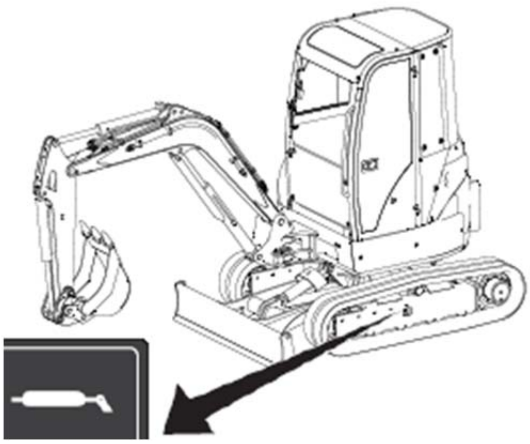

Figure 4. 13. Pallet Tension Adjustment Point of Test Compact Excavator (Mst User Maintenance Guide,2016)

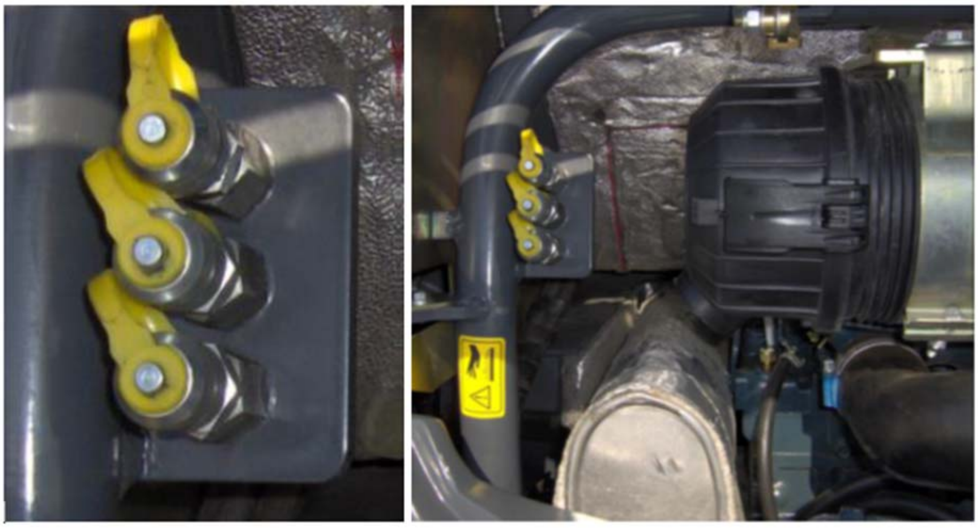

Figure 4.14. Check Points of Test Compact Excavator Hydraulic System Main Pressure Line (Mst User Maintenance Guide,2016)

Figure 4.15. Check Points of Test Compact Excavator Hydraulic System Pilot Pressure Line (Mst User Maintenance Guide,2016)

After completion of maintenance work, the compact excavator is equipped with test equipment. It is aimed to achieve the most accurate results by integrating the equipment correctly into the system. The workability of the test devices after integration was checked before the test and preliminary test records were made. The test devices are connected to the positions determined in Figure 4.16 and Figure 4.17.

Figure 4.16. Test Equipment Installation of Compact Excavator Fuel Consumption Test

Figure 4.17. Test Equipment Installation for Compact Excavator Fuel Consumption Test

4.2.2. Test Procedure for Test Compact Excavator

The compact excavators are designed and manufactured for soil work such as ditching and filling, for wall-breaking with hydraulic breakers, for construction of soil sets on hard but non-quarry floors or for agricultural work with the help of bushing, burrs or loading, sewer cleaning, ditching and mowing equipment. These machines have endothermic diesel engine. The transmission is hydrostatic, and the boom and bucket manoeuvres and an unlimited 360-degree rotation of the upper structure are controlled by servo controlled joystick.

The travel and levelling blade manoeuvres are controlled by one arm. As the machine moves on rubber pallets, it can also be used on normal floors and sidewalks.

As emphasized in the first part of the thesis, although there are many factors that affect fuel consumption, the most important are hydraulic system and internal combustion engine control. For this reason, the integration of the engine and hydraulic system is very important. In order to reduce fuel consumption and emissions, the integration of the internal combustion engine with the hydraulic system through the pump, producing as much power as needed, and the efficient transfer of the power from the engine to the attachment groups is critical.

The hydraulic excavator has a Japanese standard known as JCMAS H020 on fuel consumption measurement. However, according to this standard, the machine performs fuel consumption tests according to certain actions determined, not according to all the work performed under real working conditions. According to this standard, movements are determined as trench digging, soiling, straight traveling and low idling standby. (Zarotti,2009)

In this thesis, while fuel consumption tests were performed on the machine, trench digging, soil levelling, straight travelling and low idling standby stages were determined by field observations and mixed fuel consumption values were obtained as a result of the operation of the machine for one hour. These tests based on actual operating conditions provide more accurate information about fuel consumption.

The test was planned in real working conditions. The engine rpm for testing are determined according to the power performance curve of the engine. In addition to fuel consumption, upper frame turning speed, boom cycle time, arm cycle time, bucket cycle time, pressure values in hydraulic lines and flow values were recorded at the specified rpm. Specified test motor rpm values, 1400, 1550, 1700, 2000, 2150, 2300, 2450 and 2600 rpm. In these engine rpm, the machine has worked for one hour for each specified rpm value, and the data has been recorded in all previously mentioned titles. For each test rpm, one hour work, 15% straight travelling, 60% trench digging, 18% soil levelling and 7% low idling standby were determined and results data were recorded for each cycle. All tests carried out by the same operator in order to prevent any differences that may arise from the driver.

Figure 4.18. Figure in the Test Moment When Receiving Cycle Time

Figure 4.19. Figure in the Test Moment When Receiving Cycle Time

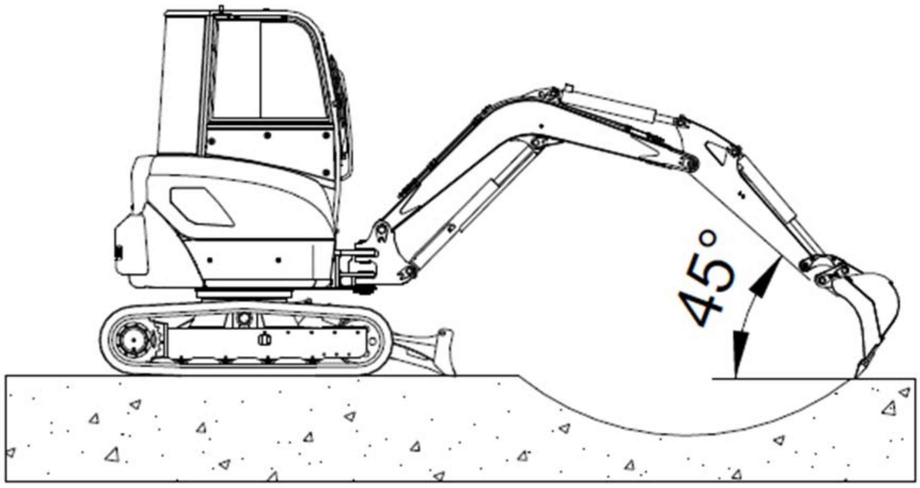

Figure 4.20. Digging Position of Compact Excavator (Mst User Maintenance Guide,2016)

On the other hand, an important point about digging efficiency is the digging angle between the arm and the ground. When excavating, the digging angle should be 45 degrees as shown in Figure 4.21.

5. RESULTS AND DISCUSSION

In this section of the thesis, instantaneous fuel consumption, total fuel consumption, hydraulic flow, hydraulic pressure, boom cycle time, arm cycle time, bucket cycle time and upper frame turning cycle time values are presented for specified engine rpm.

5.1. The Fuel Consumption, Pressure and Hydraulic Flow Test Results at 1400 Engine RPM

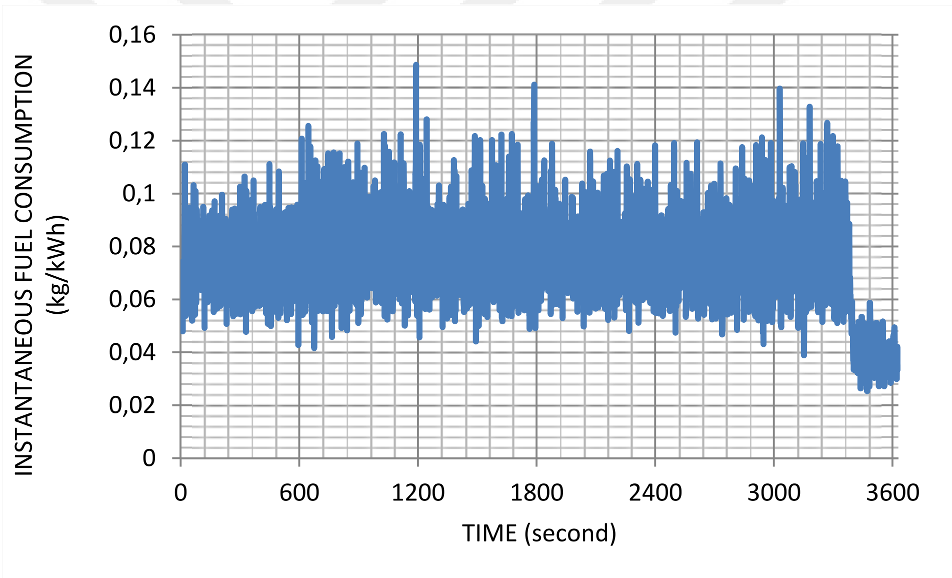

Figure 5.1. Test Results of Instantaneous Fuel Consumption at 1400 RPM

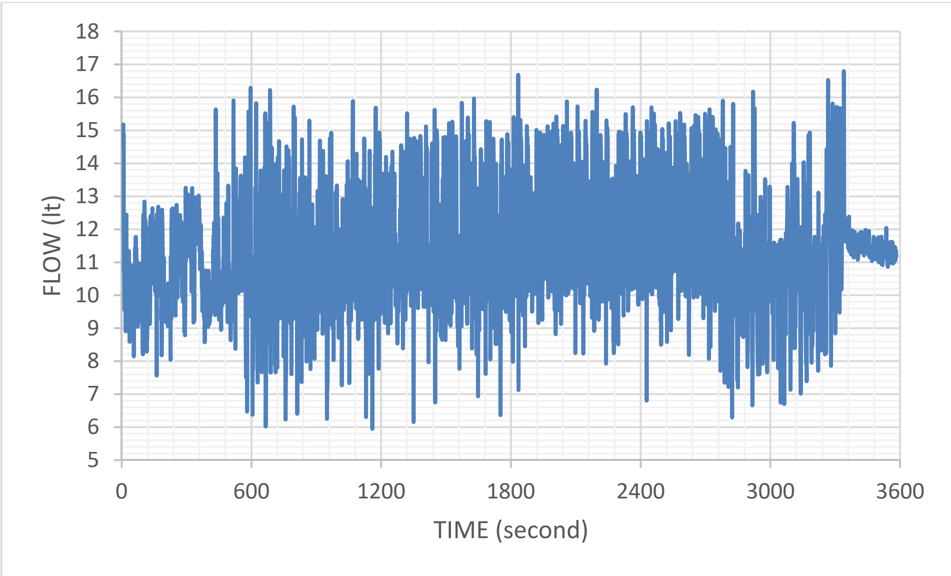

Figure 5.2. Test Results of P1 Flow at 1400 RPM

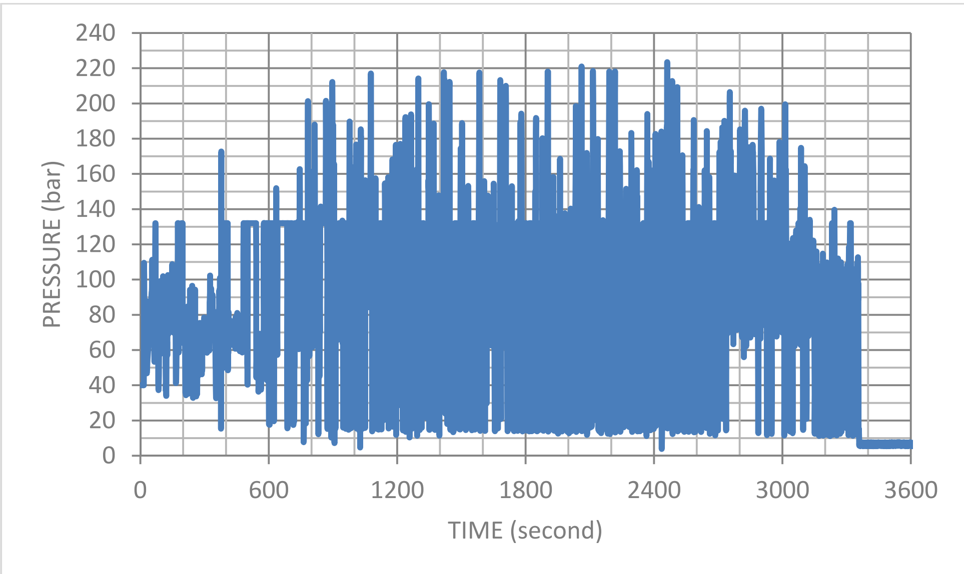

Figure 5.3. Test Results of P1 Pressure at 1400 RPM

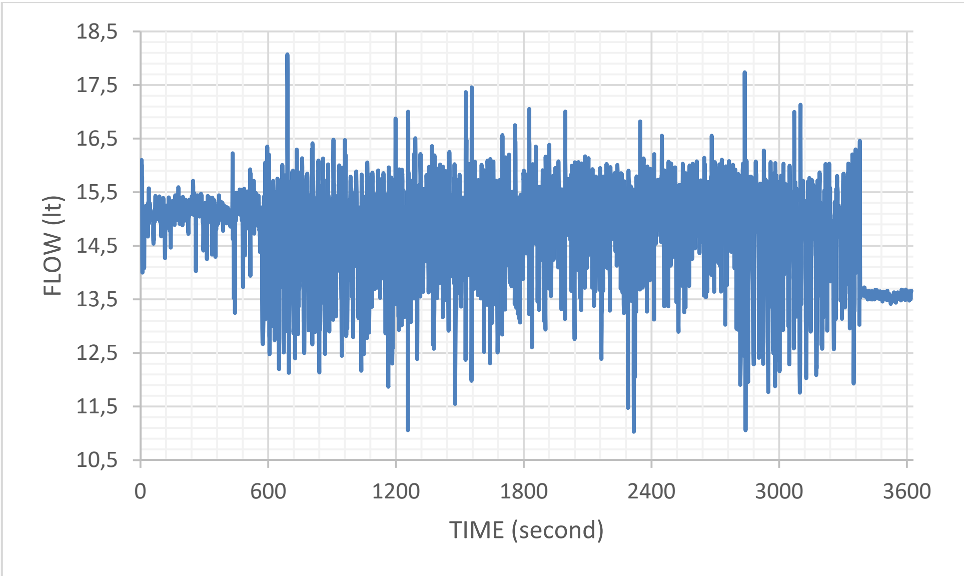

Figure 5.4. Test Results of P3 Flow at 1400 RPM

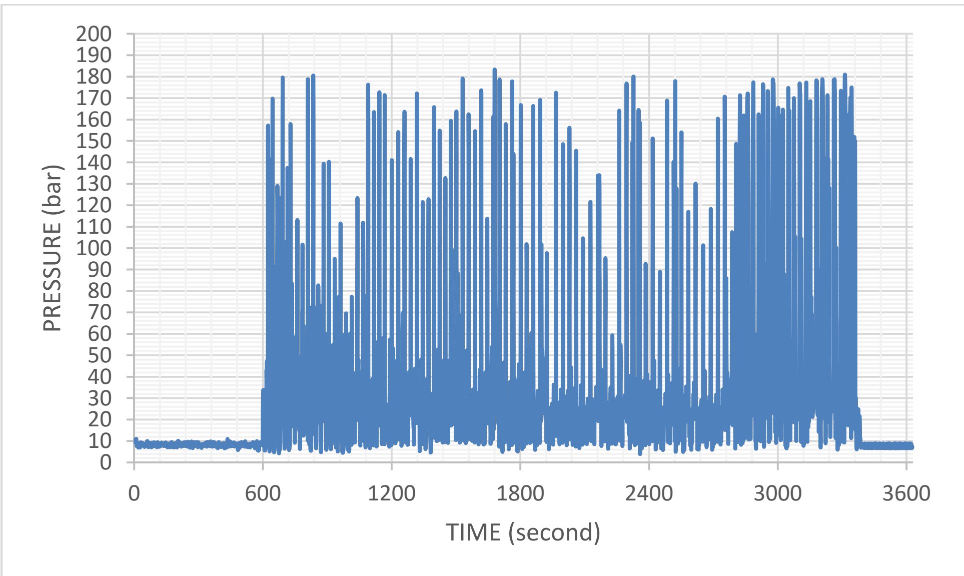

Figure 5.5. Test Results of P3 Pressure at 1400 RPM

When pressure, flow rate and fuel consumption charts are examined for 1400 rpm, instant changes in the hydraulic system and engine during the operation of the hydraulic compact excavator are clearly observed. The reaction of the hydraulic system during operation is reflected in the flow and pressure charts. Likewise, instant fuel consumption data is important for the optimization of the system.

5.2. The Fuel Consumption, Pressure and Hydraulic Flow Test Results at 1550 Engine RPM

When the data is analyzed for 1500 rpm, the reaction of the hydraulic system has become a bit more stable. Even though fuel consumption values have increased compared to 1400 cycles, hydraulic flow and pressure values show that the capacity to do work increases.

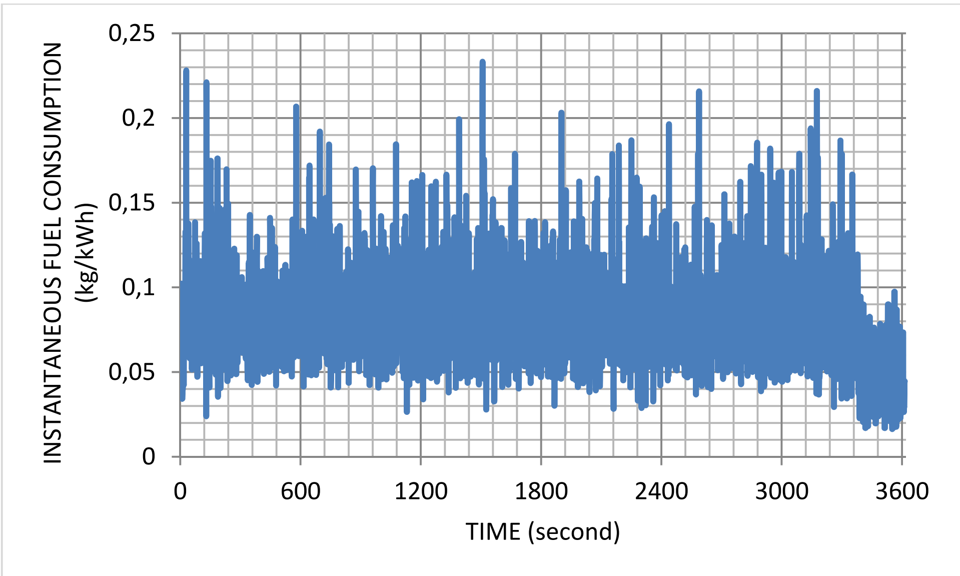

Figure 5.6. Test Results of Instantaneous Fuel Consumption at 1550 RPM

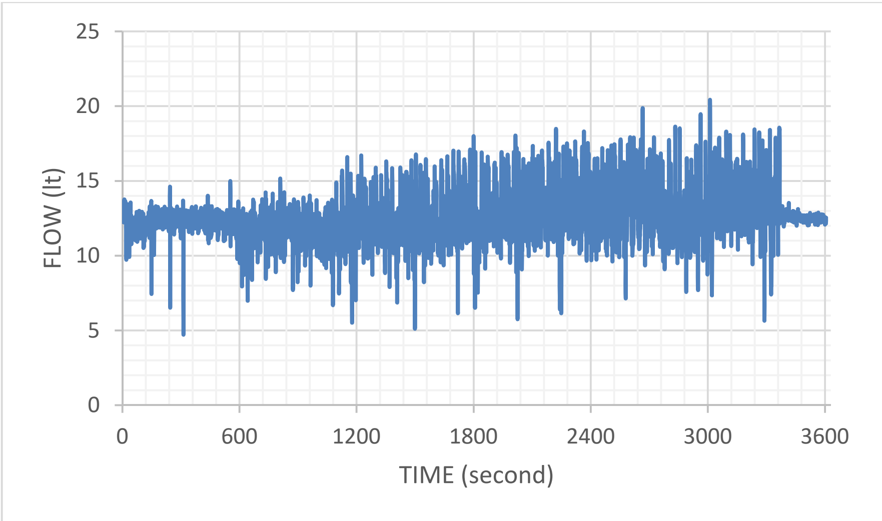

Figure 5.7. Test Results of P1 Flow at 1550 RPM

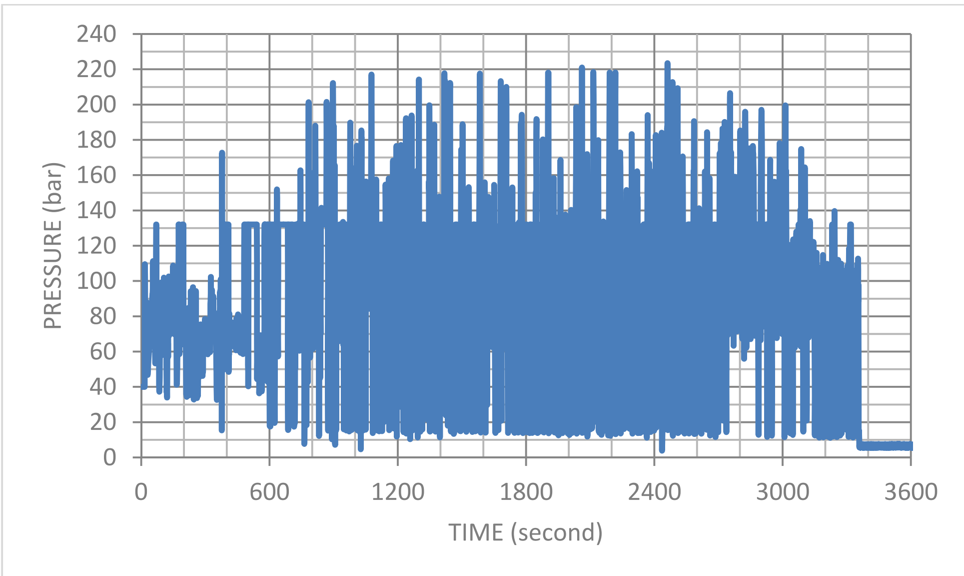

Figure 5.8. Test Results of P1 Pressure at 1550 RPM

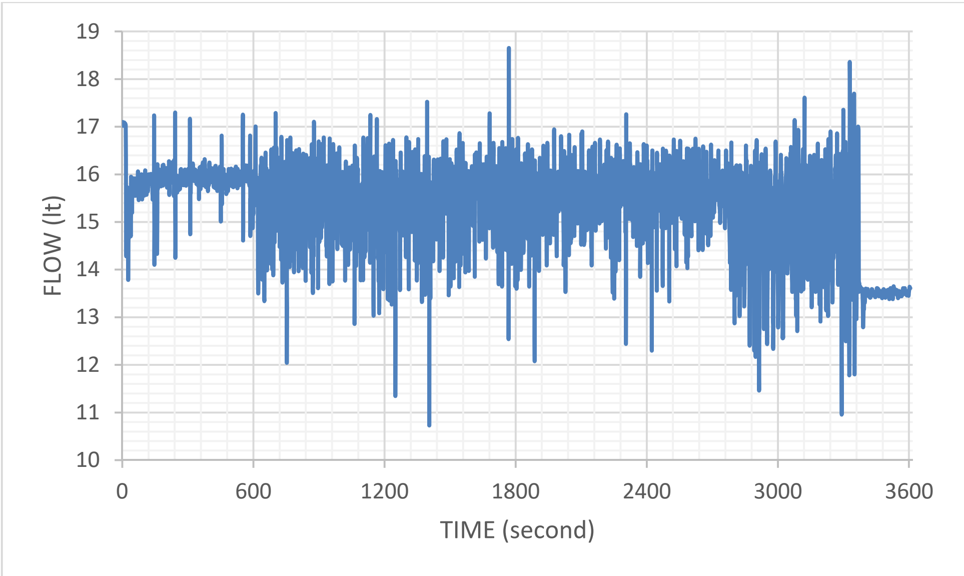

Figure 5.9. Test Results of P3 Flow at 1550 RPM

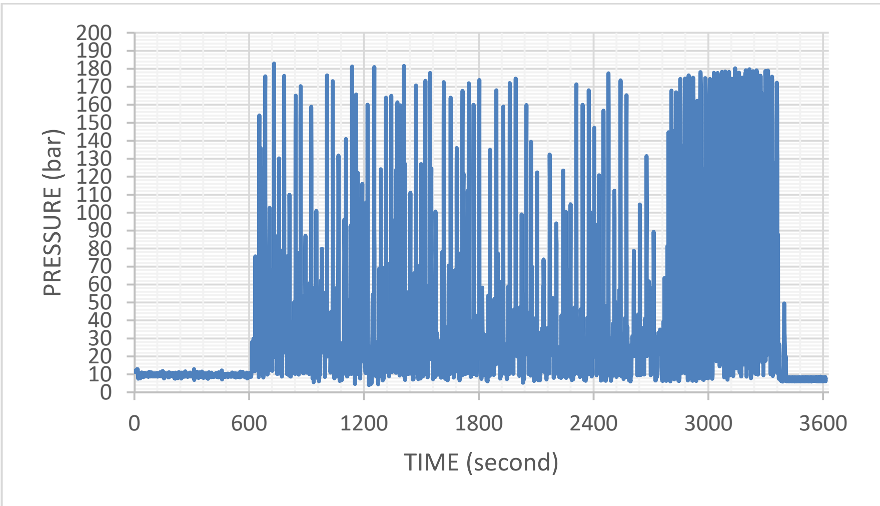

Figure 5.10. Test Results of P3 Pressure at 1550 RPM

5.3. The Fuel Consumption, Pressure and Hydraulic Flow Test Results at 1700 Engine RPM

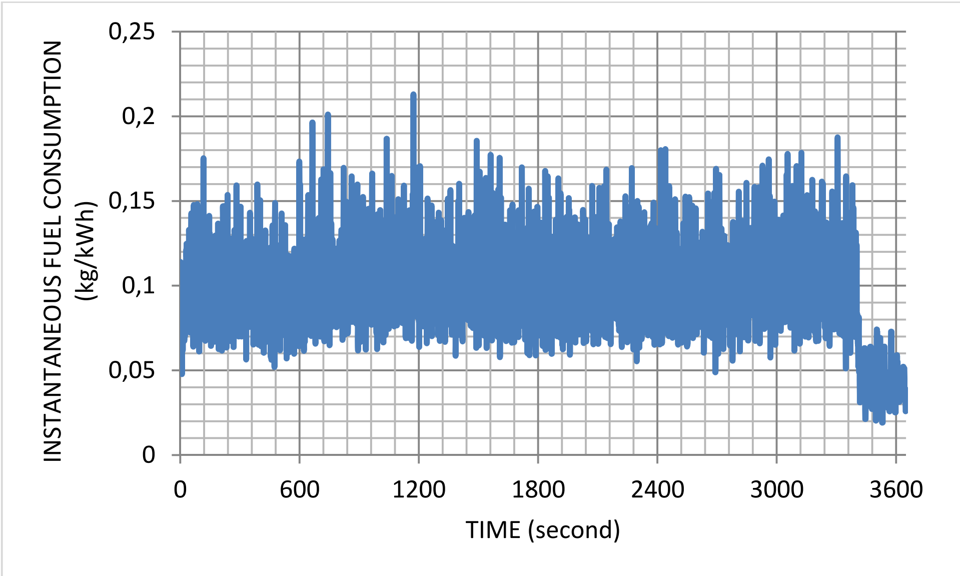

Figure 5.11. Test Results of Instantaneous Fuel Consumption at 1700 RPM

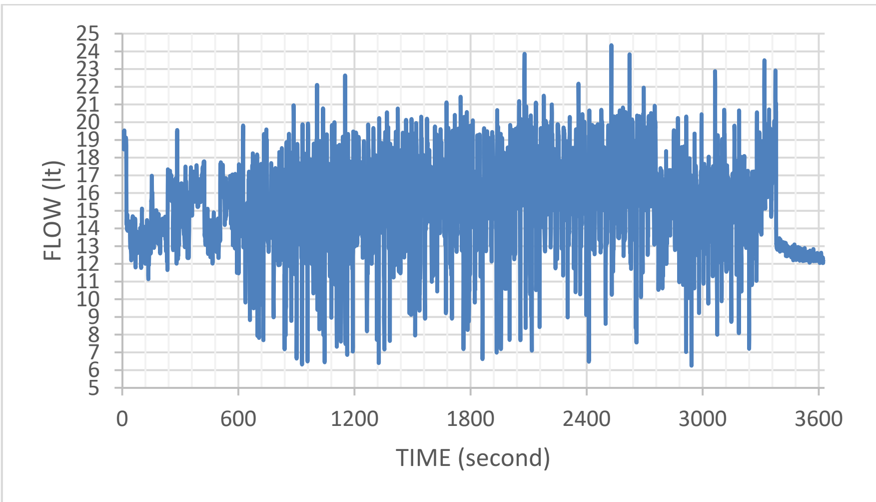

Figure 5.12. Test Results of P1 Flow at 1700 RPM

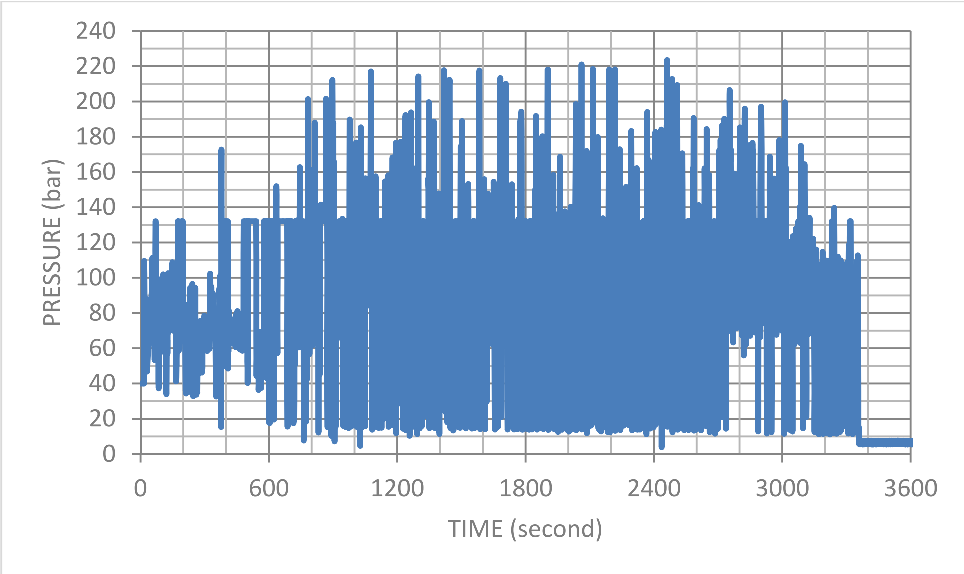

Figure 5.13. Test Results of P1 Pressure at 1700 RPM

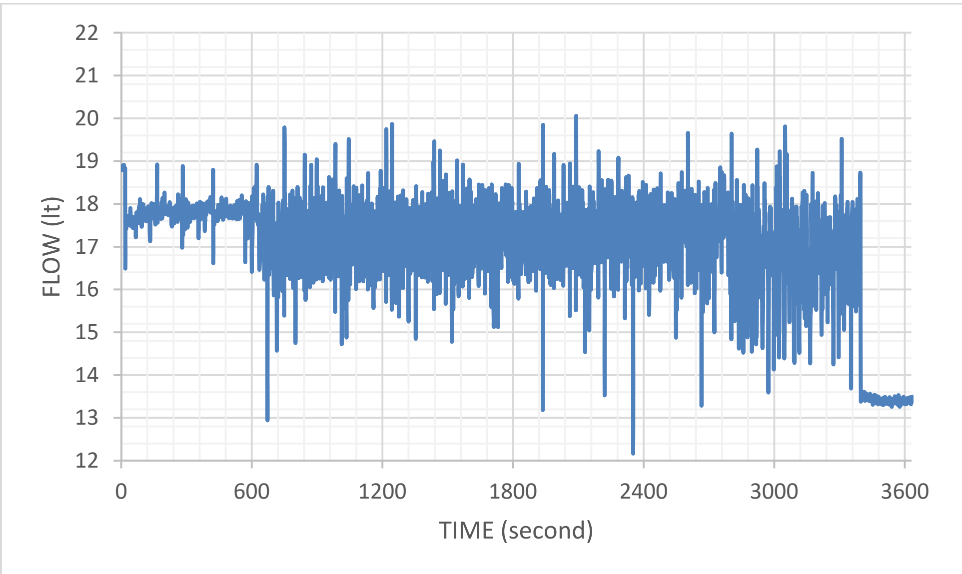

Figure 5.14. Test Results of P3 Flow at 1700 RPM

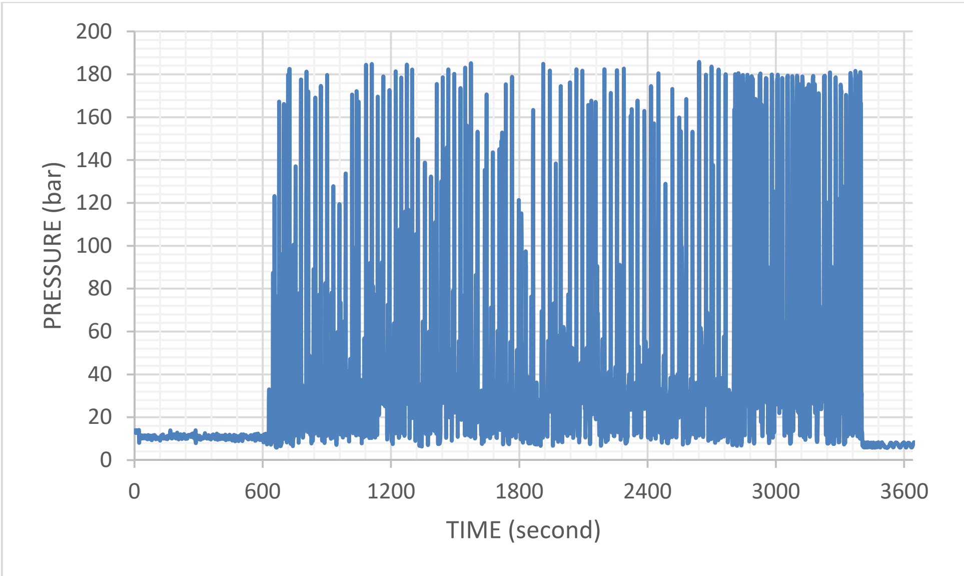

Figure 5.15. Test Results of P3 Pressure at 1700 RPM

When the data obtained for the 1700 engine rpm are examined, improvements in hydraulic pressure and flow rates are observed. In addition, fuel consumption has increased proportionally compared to the results obtained at lower engine rpm.

5.4. The Fuel Consumption, Pressure and Hydraulic Flow Test Results at 2000 Engine RPM

When we arrived at the 2000 engine rpm, it was observed that the hydraulic system reacts more strongly and the capacity to do work is approaching the desired levels.

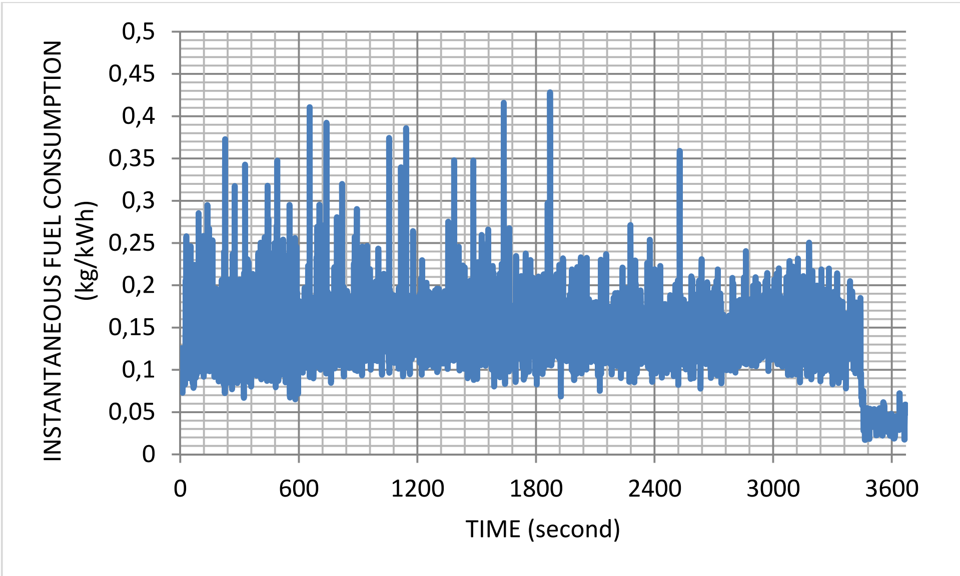

Figure 5.16. Test Results of Instantaneous Fuel Consumption at 2000 RPM

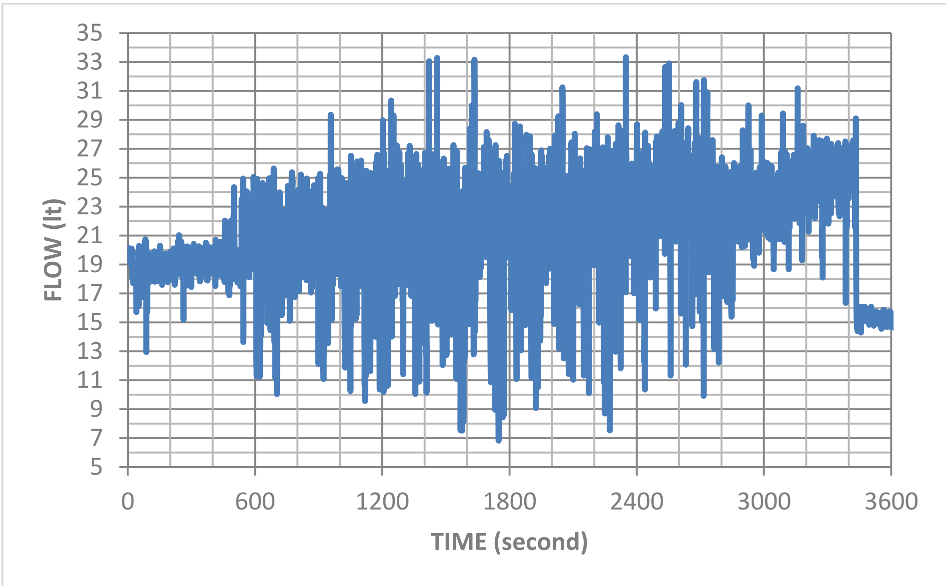

Figure 5.17. Test Results of P1 Flow at 2000 RPM

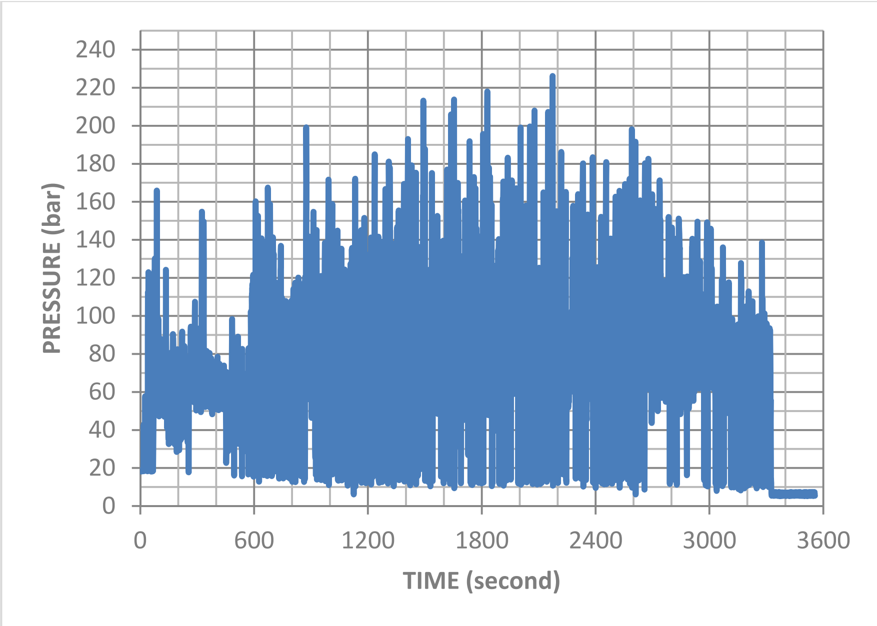

Figure 5.18. Test Results of P1 Pressure at 2000 RPM

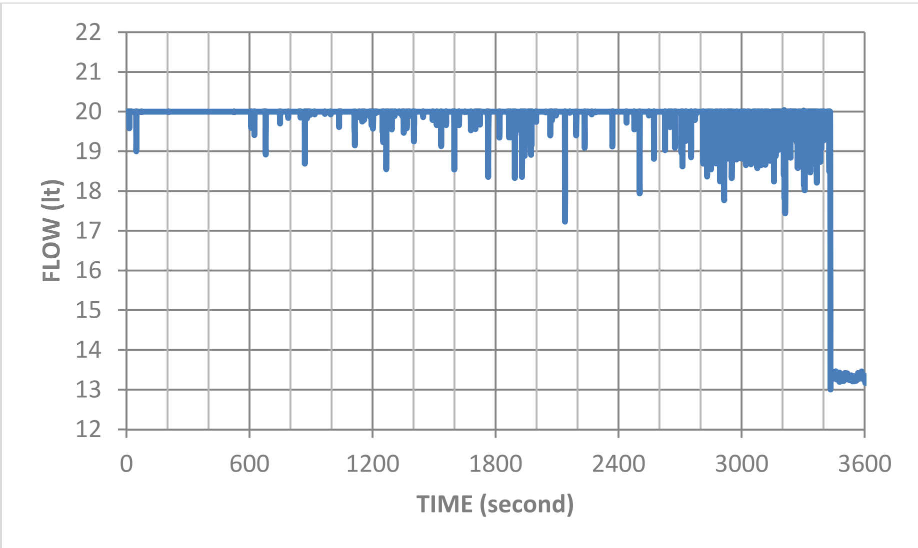

Figure 5.19. Test Results of P3 Flow at 2000 RPM

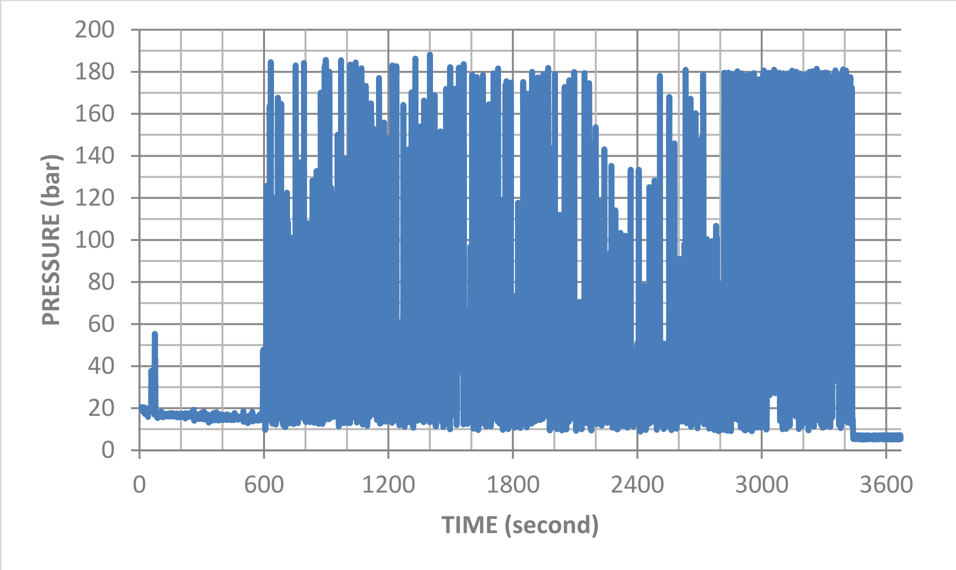

Figure 5.20. Test Results of P3 Pressure at 2000 RPM

5.5. The Fuel Consumption, Pressure and Hydraulic Flow Test Results at 2150 Engine RPM

When the results of the 2150 engine rpm were examined, the hydraulic pressure and flow values were found to be at the appropriate values for the operation. In addition, fuel consumption values have increased compared to previous rpms, but can be said to be in a productive range in terms of work.

In addition, it has been observed that significantly improvement in the speed of the machine has started with this rpm.

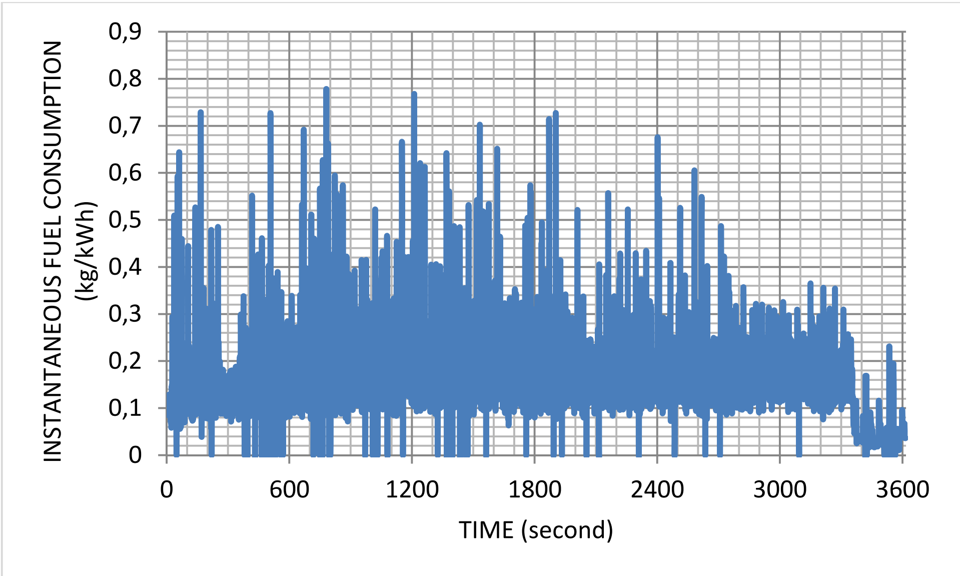

Figure 5.21. Test Results of Instantaneous Fuel Consumption at 2150 RPM

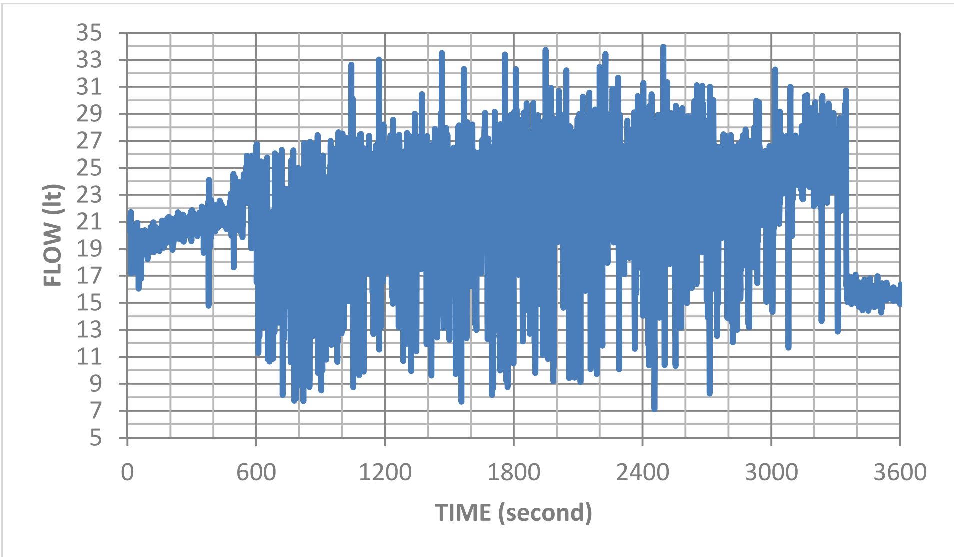

Figure 5.22. Test Results of P1 Flow at 2150 RPM

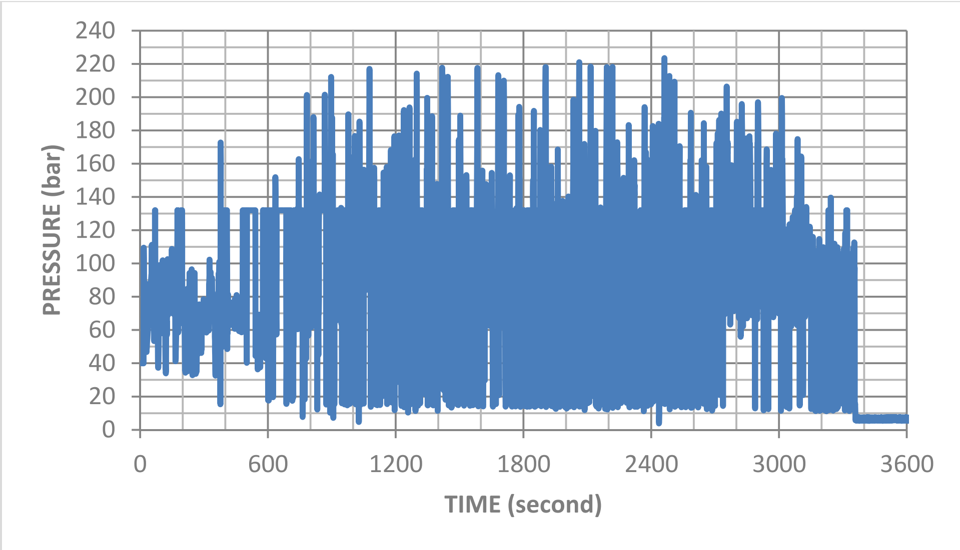

Figure 5.23. Test Results of P1 Pressure at 2150 RPM

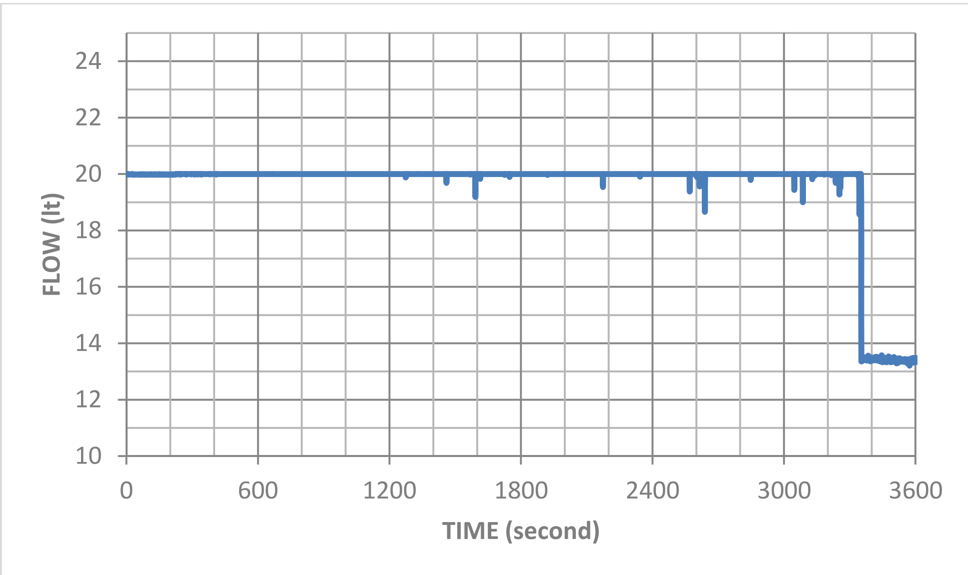

Figure 5.24. Test Results of P3 Flow at 2150 RPM

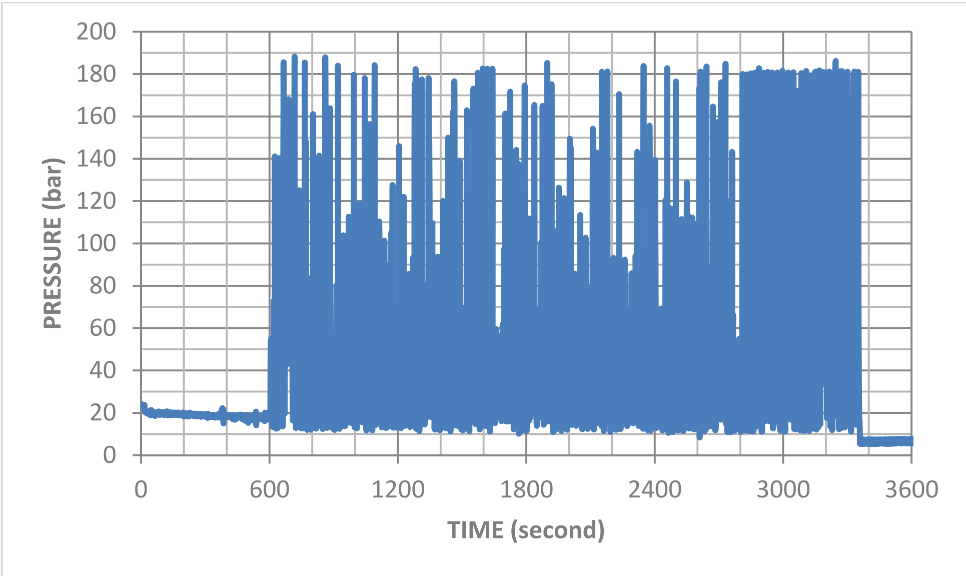

Figure 5.25. Test Results of P3 Pressure at 2150 RPM

5.6. The Fuel Consumption, Pressure and Hydraulic Flow Test Results at 2300 Engine RPM

When the results of the 2300 engine transfer are examined, the increase in hydraulic compact excavator capacity can be seen clearly.The increase in hydraulic flow and pressure values shows that the machine works more quickly.

Although the improvement in the hydraulic system has increased fuel consumption, it can be said to be efficient when considering the work to be done at the time of the unit.

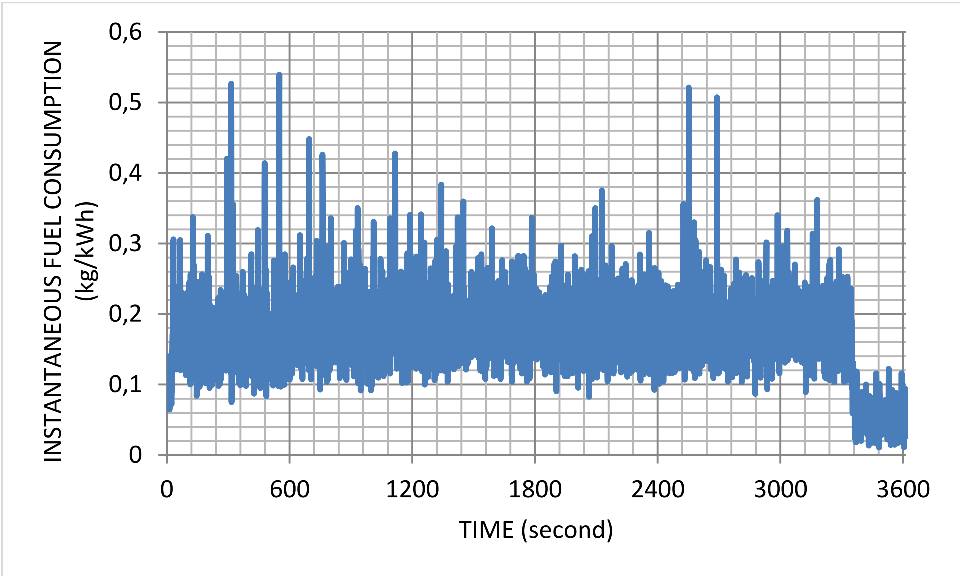

Figure 5.26. Test Results of Instantaneous Fuel Consumption at 2300 RPM

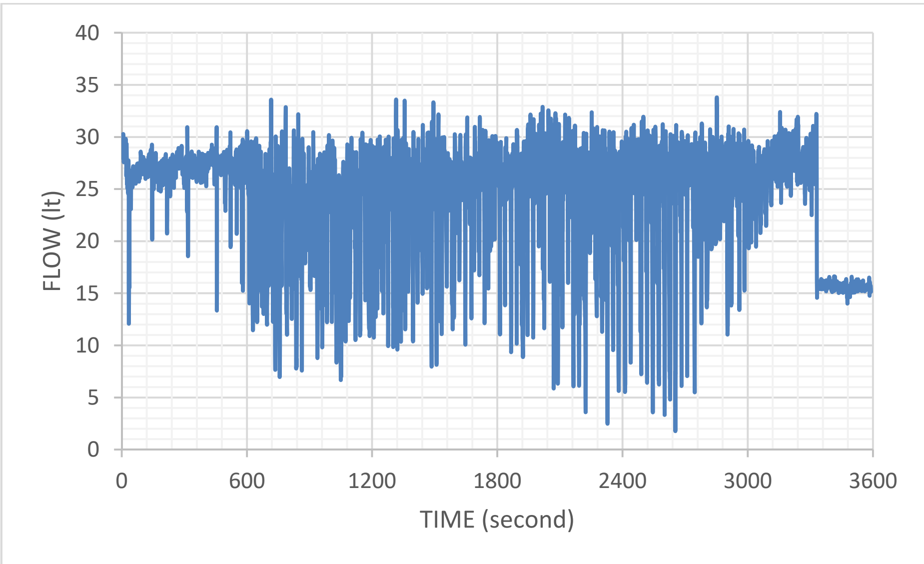

Figure 5.27. Test Results of P1 Flow at 2300 RPM

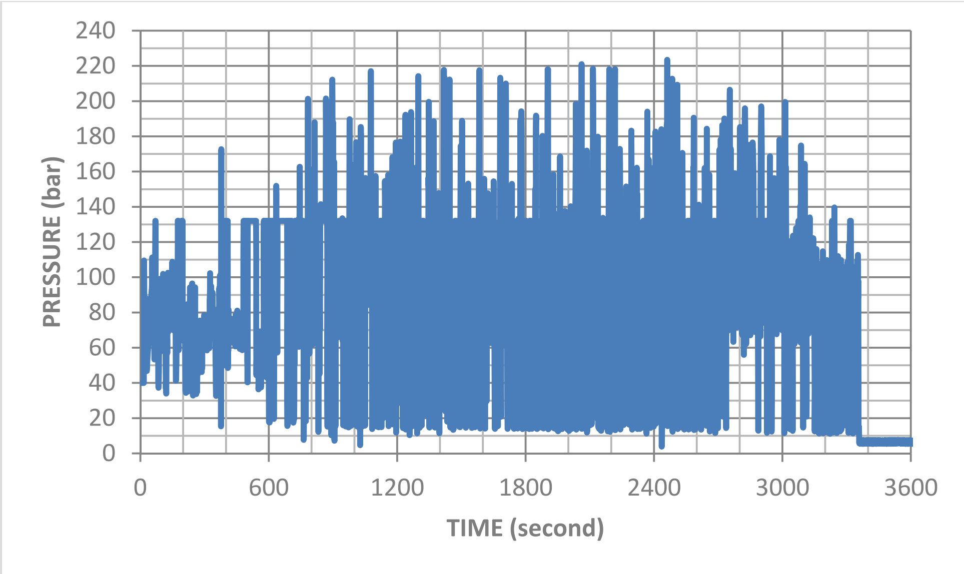

Figure 5.28. Test Results of P1 Pressure at 2300 RPM

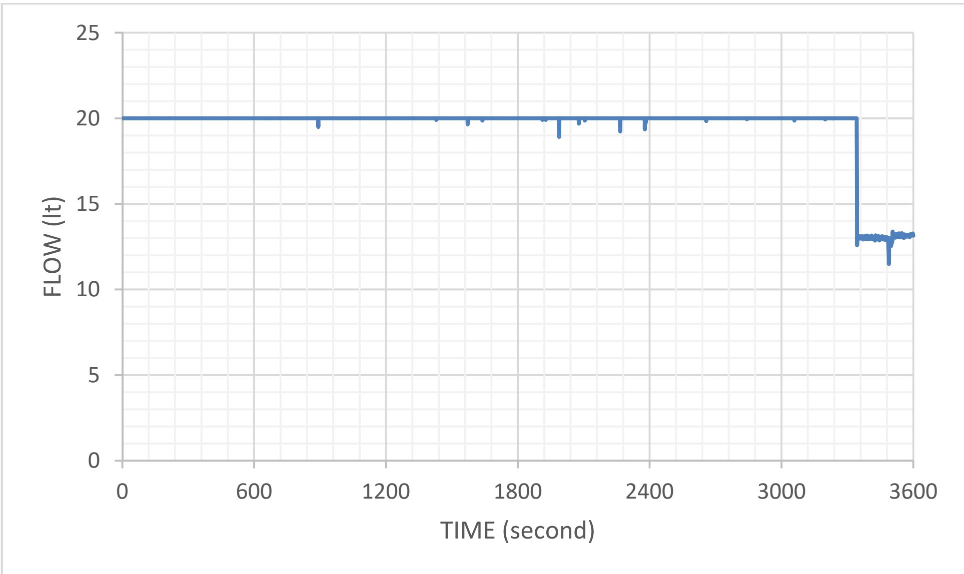

Figure 5.29. Test Results of P3 Flow at 2300 RPM

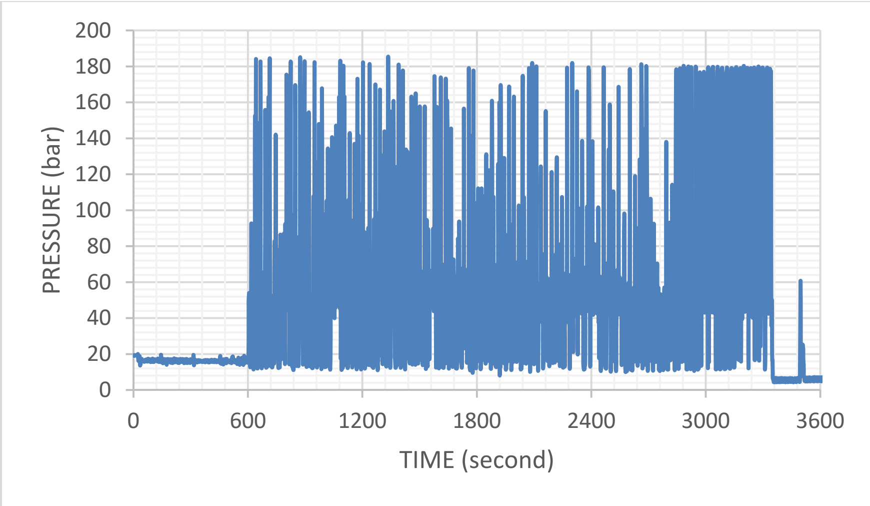

Figure 5.30. Test Results of P3 Pressure at 2300 RPM

5.7. The Fuel Consumption, Pressure and Hydraulic Flow Test Results at 2450 Engine RPM

When we come to the results obtained from the test carried out for the 2450 engine rpm, it is observed that hydraulic pressure and flow values increase for hydraulic compact excavator. In addition, the capacity to do work has increased at the same rate. When the fuel consumption chart is examined, the value range can be seen throughout the working. Although the total fuel consumption value has increased, it can be said that it is appropriate to work efficiently according to the difficulty of the work to be done.

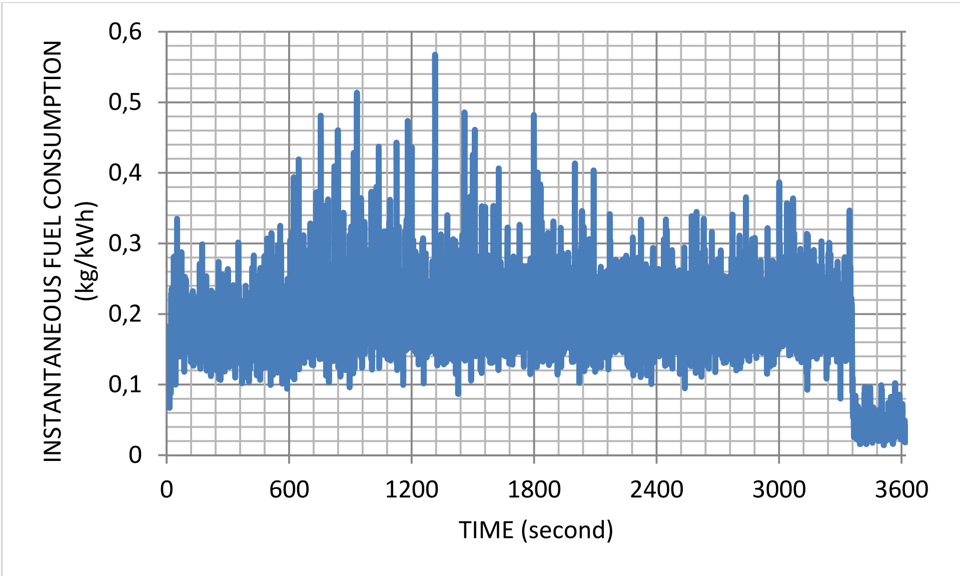

Figure 5.31. Test Results of Instantaneous Fuel Consumption at 2450 RPM

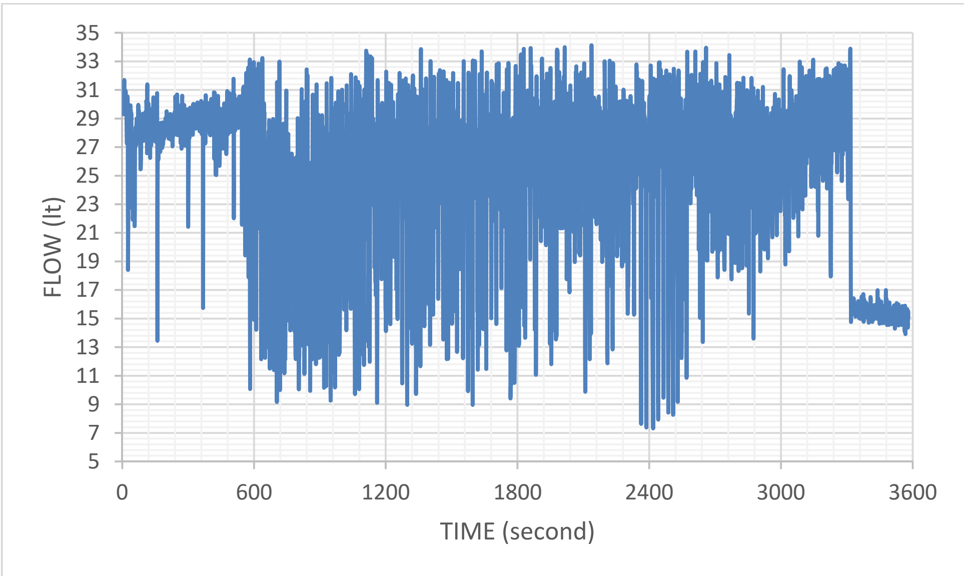

Figure 5.32. Test Results of P1 Flow at 2450 RPM

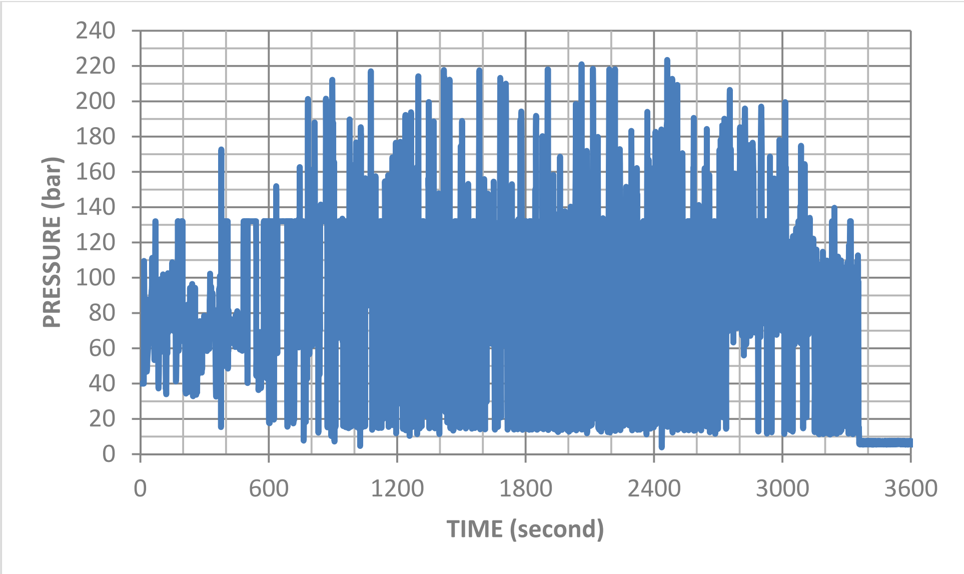

Figure 5.33. Test Results of P1 Pressure at 2450 RPM

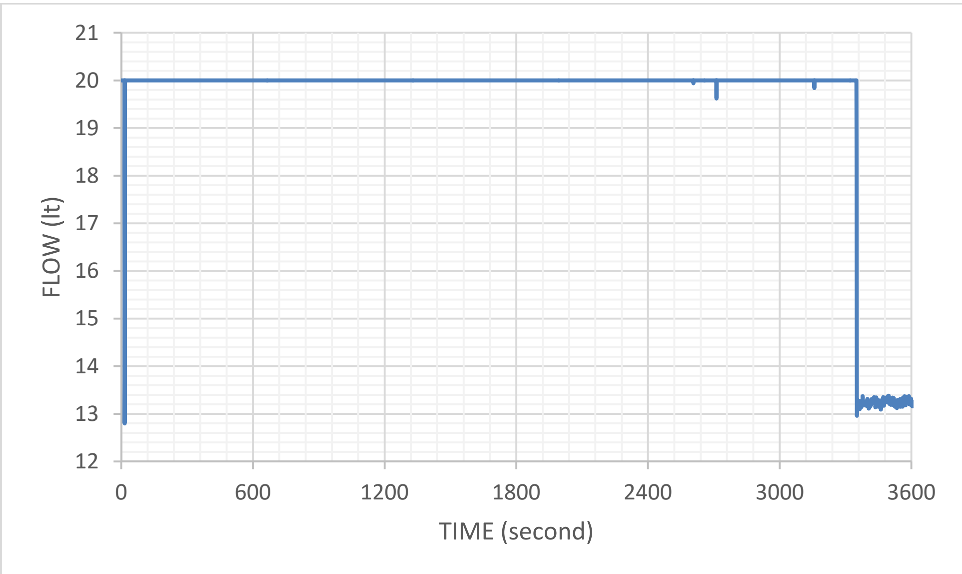

Figure 5.34. Test Results of P3 Flow at 2450 RPM

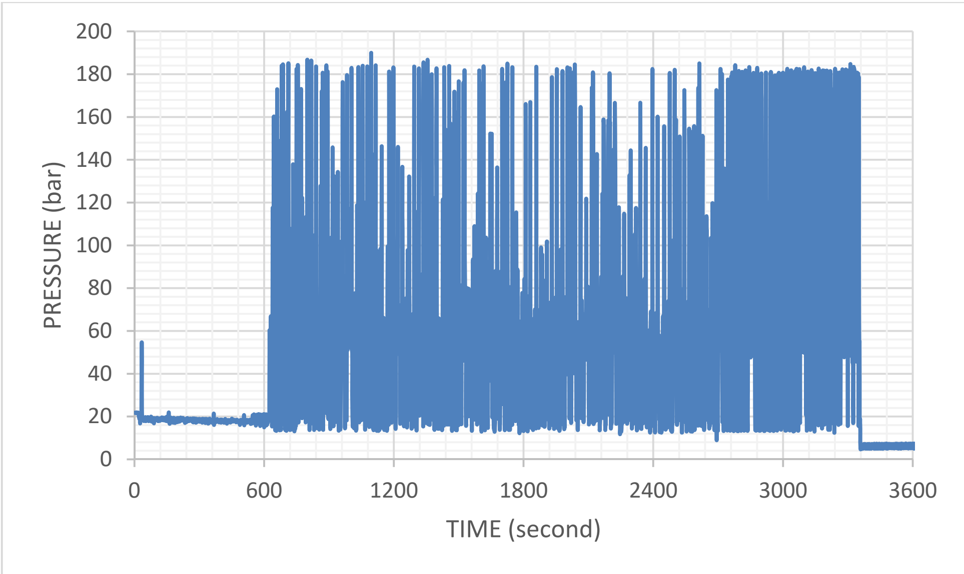

Figure 5.35. Test Results of P3 Pressure at 2450 RPM

5.8. The Fuel Consumption, Pressure and Hydraulic Flow Test Results at 2600 Engine RPM

When the results of the 2600 engine rpm were examined, it was observed that the fuel consumption increased at a higher rate even if the hydraulic pressure and flow values were improved. In addition, when the reactions of the hydraulic system were examined, the results were found to be at the limit values. Although the work was faster than the previous rpm, it was found that it was not suitable in terms of efficiency.

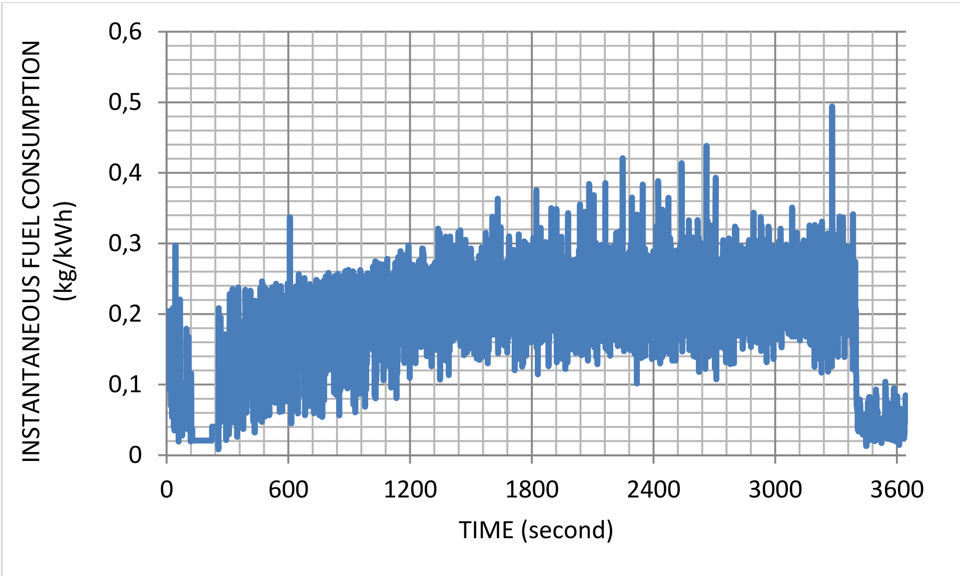

Figure 5.36. Test Results of Instantaneous Fuel Consumption at 2600 RPM

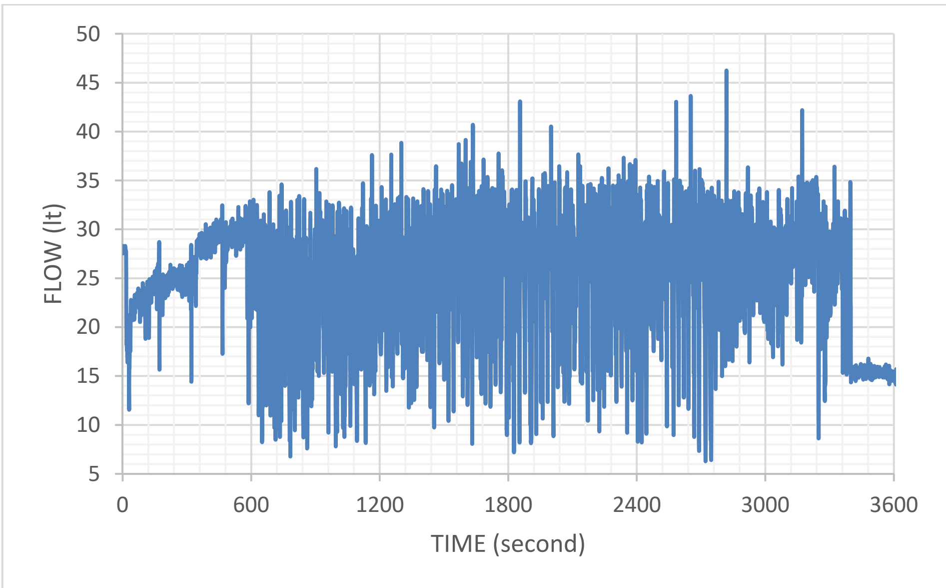

Figure 5.37. Test Results of P1 Flow at 2600 RPM

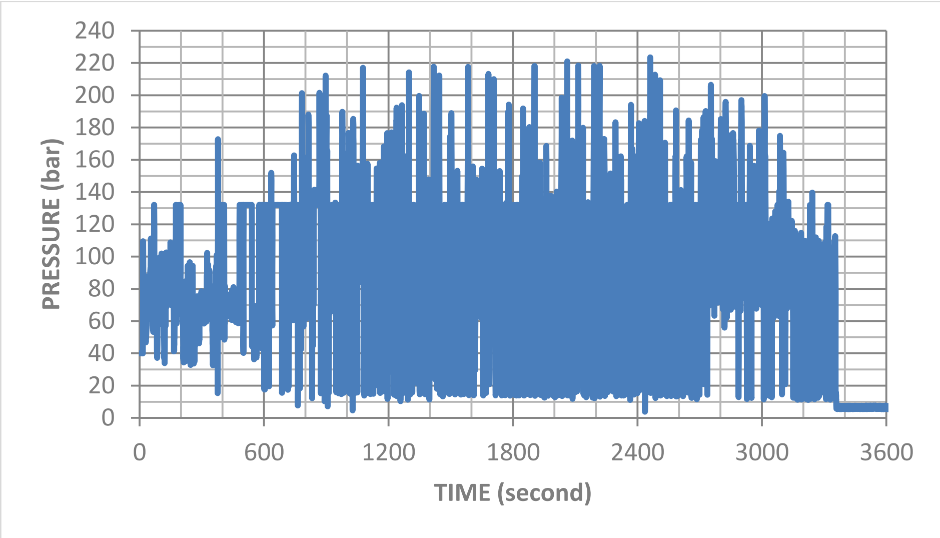

Figure 5.38. Test Results of P1 Pressure at 2600 RPM

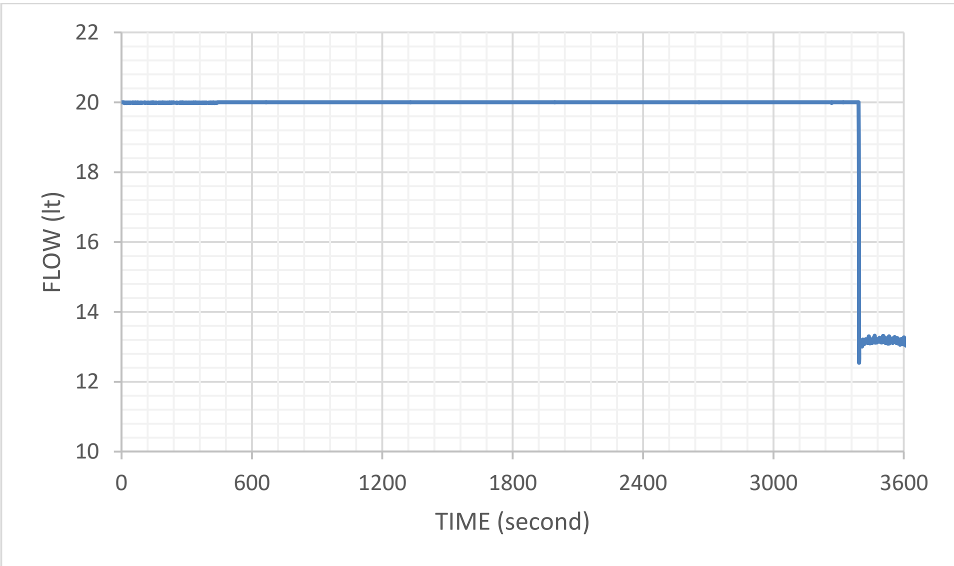

Figure 5.39. Test Results of P3 Flow at 2600 RPM

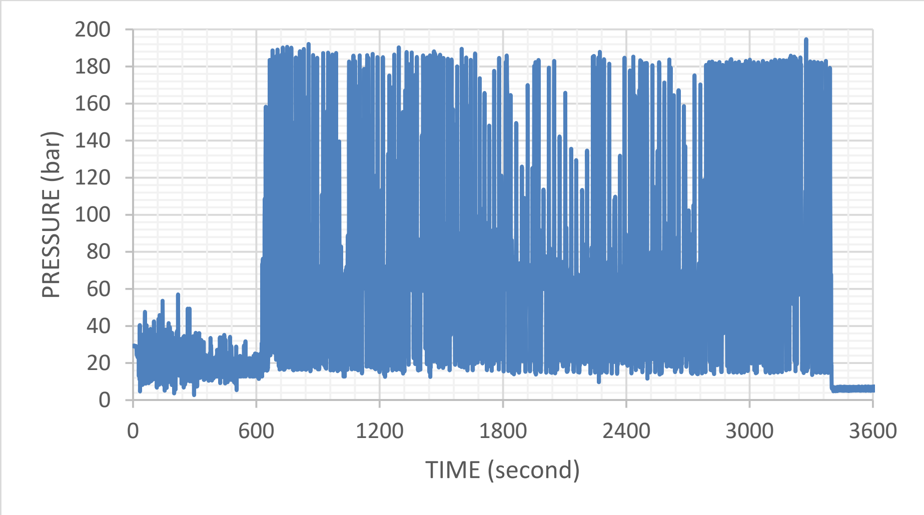

Figure 5.40. Test Results of P3 Pressure at 2600 RPM

5.9. The Total Fuel Consumption and Cycle Time Test Results for All Engine Test RPM

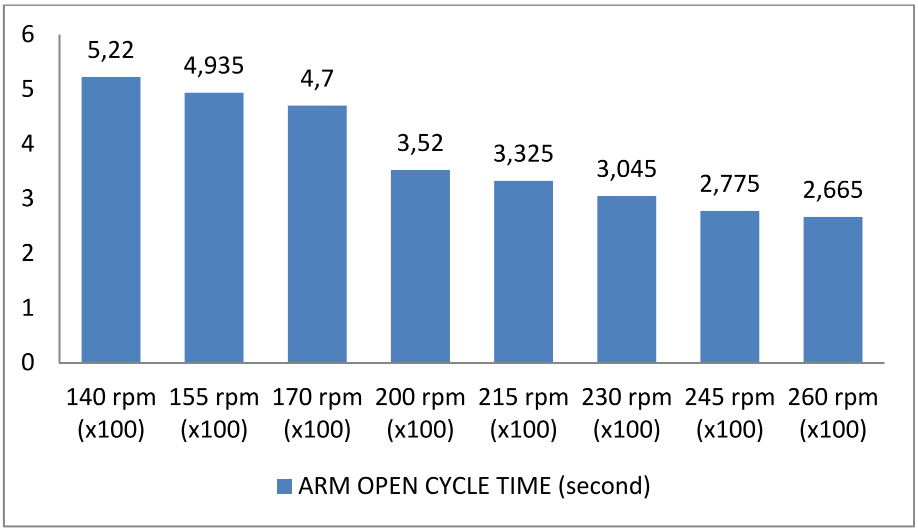

Figure 5.41. Test Results of Arm Open Cycle Time

Table 5.1. Comparison Value of Arm Open Cycle Time

ENGINE RPM (x100)	ARM OPEN CYCLE TIME (second)
140	5,22
155	4,935
170	4,7
200	3,52
215	3,325
230	3,045
245	2,775
260	2,665

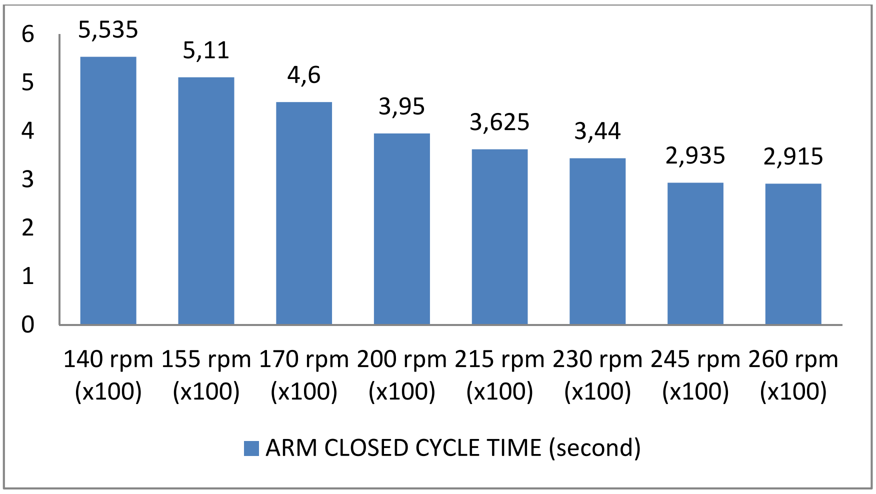

Figure 5.42. Test Results of Arm Closed Cycle Time

Table 5.2. Comparison Value of Arm Closed Cycle Time

ENGINE RPM (x100)	ARM CLOSED CYCLE TIME (second)
140	5,535
155	5,11
170	4,6
200	3,95
215	3,625
230	3,44
245	2,935
260	2,915

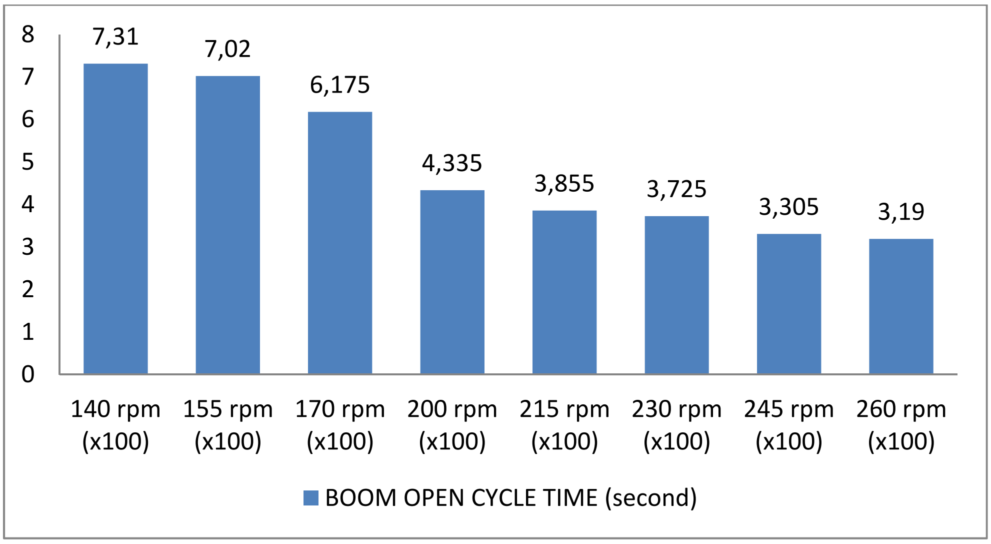

Figure 5.43. Test Results of Boom Open Cycle Time

Table 5.3. Comparison Value of Boom Open Cycle Time

ENGINE RPM (x100)	BOOM OPEN CYCLE TIME (second)
140	7,31
155	7,02
170	6,175
200	4,335
215	3,855
230	3,725
245	3,305
260	3,19

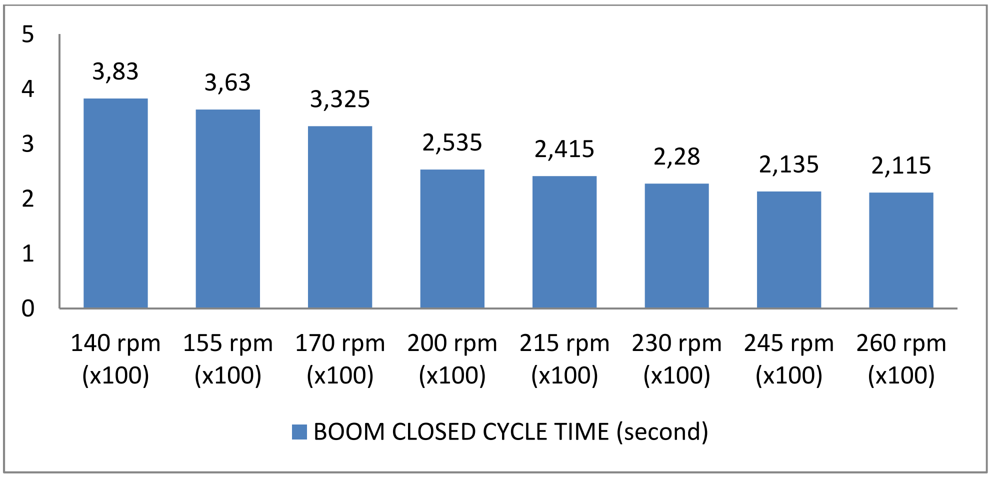

Figure 5. 44. Test Results of Boom Closed Cycle Time

Table 5.4. Comparison Value of Boom Closed Cycle Time

ENGINE RPM (x100)	BOOM CLOSED CYCLE TIME (second)
140	3,83
155	3,63
170	3,325
200	2,535
215	2,415
230	2,28
245	2,135
260	2,115

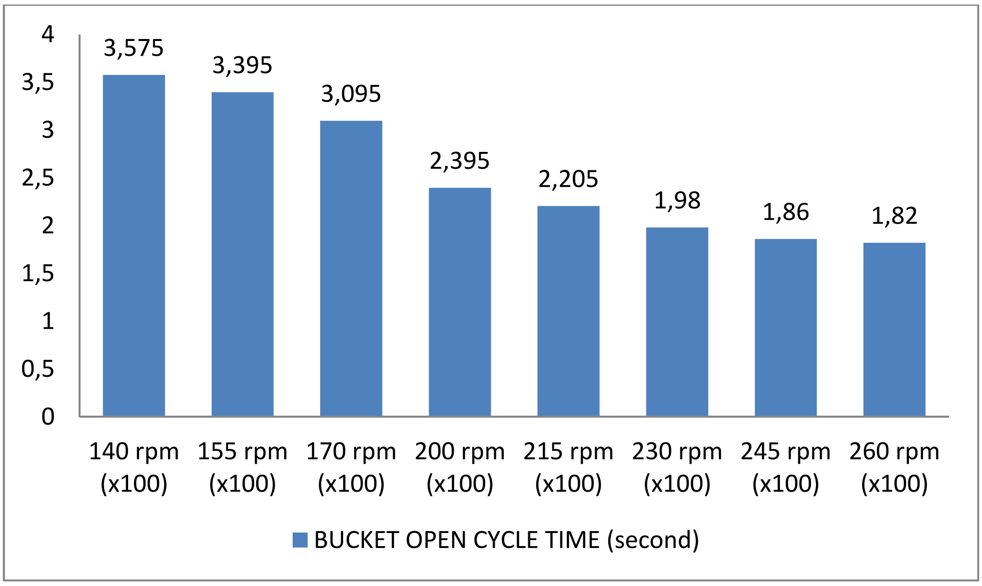

Figure 5.45. Test Results of Bucket Open Cycle Time

Table 5.5. Comparison Value of Bucket Open Cycle Time

ENGINE RPM (x100)	BUCKET OPEN CYCLE TIME (second)
140	3,575
155	3,395
170	3,095
200	2,395
215	2,205
230	1,98
245	1,86
260	1,82

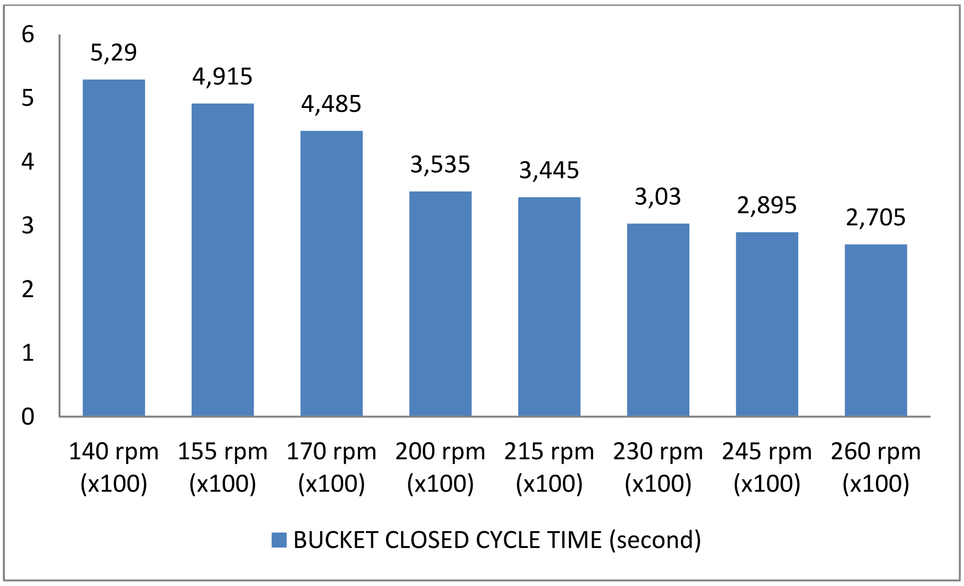

Figure 5.46. Test Results of Bucket Closed Cycle Time

Table 5.6. Comparison Value of Bucket Closed Cycle Time

ENGINE RPM (x100)	BUCKET CLOSED CYCLE TIME (second)
140	5,29
155	4,915
170	4,485
200	3,535
215	3,445
230	3,03
245	2,895
260	2,705

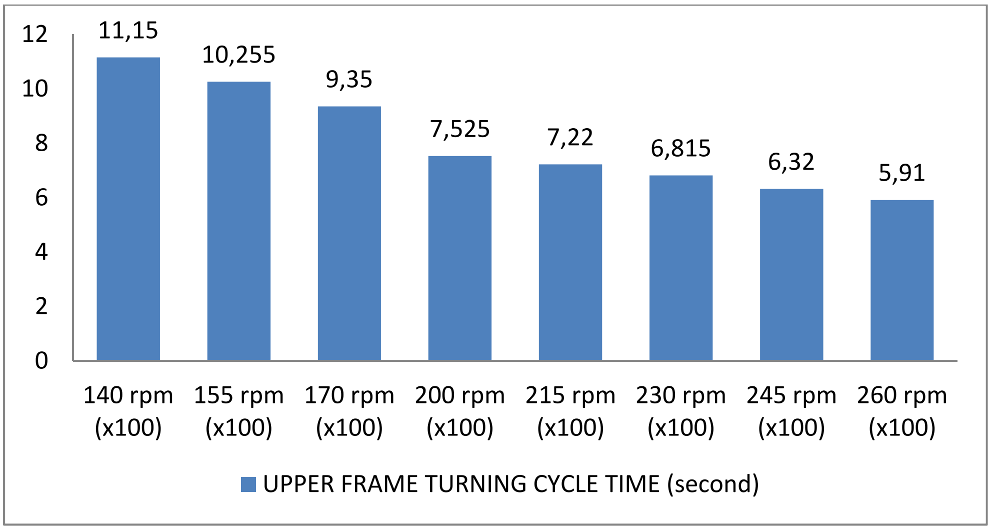

Figure 5.47. Test Results of Upper Frame Turning Cycle Time

Table 5.7. Comparison Value of Upper Frame Turning Cycle Time

ENGINE RPM (x100)	UPPER FRAME TURNING CYCLE TIME (second)
140	11,15
155	10,255
170	9,35
200	7,525
215	7,22
230	6,815
245	6,32
260	5,91

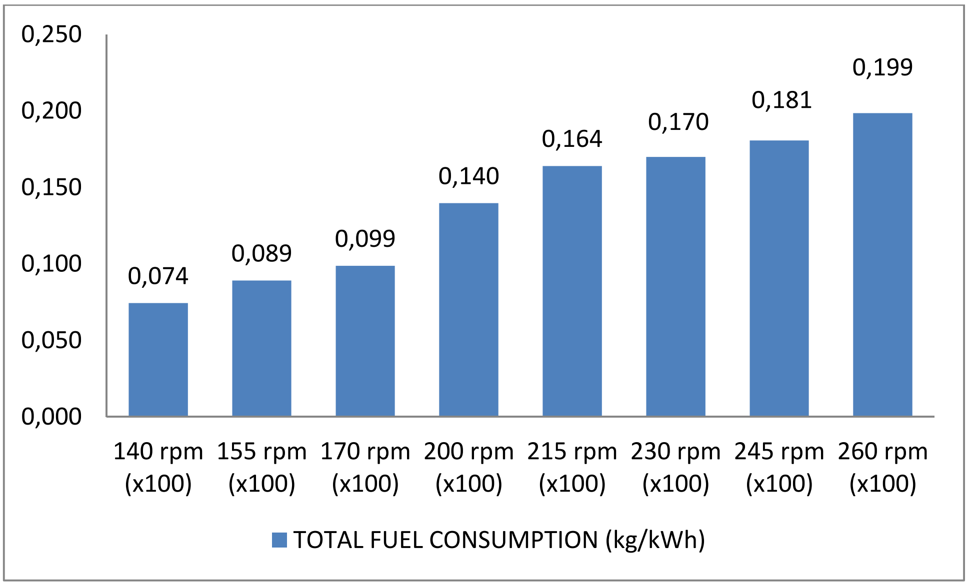

Figure 5.48. Comparison Value of Total Fuel Consumption

Table 5.8. Comparison Value of Total Fuel Consumption

ENGINE RPM (x100)	TOTAL FUEL CONSUMPTION (kg/kWh)
140	0.074
155	0.089
170	0.099
200	0.140
215	0.164
230	0.170
245	0.181
260	0.199

When the test results were evaluated, it was observed that although the machine's fuel consumption at 1400 rpm was at the lowest level, there was not enough flow rates for working in real operating conditions and the movements of the compact excavator were very slow. While fuel consumption increased at 1550 rpm, it was observed that cycle time values were to be around 5% to 8% better than 1400 rpm, but the hydraulic system could not provide sufficient power during excavation. For 1700 rpm with maximum torque, the results are better than before. When the cycle time values are examined, a significant improvement is observed around 5% to 12% according to 1550 rpm, but the hydraulic system can not show the desired performance during operation. In the test carried out at 2000 rpm, hydraulic system flow and pressure values approximated the desired operating values that around 15% to 30% better than 1700 rpm. In addition, the obtained cycle time data appears to be suitable for studies on soft surfaces. When the pressure, flow rate, cycle time and fuel consumption values for the 2150 rpm are analysed, the values show that the machine is faster around 3% to 11% according to 2000 rpm and closer to efficient working points. It was observed that the cycle time data of the machine for 2300 rpm were more suitable for a brisk operation, cycle time values were to be around 3% to 12% better than 2150 rpm, and although fuel consumption increased proportionally, it was more efficient for the unit to do more work at the time. 2450 rpm performance tables were examined in detail, pressure and flow values were more stable, so it was observed that the study was done more quickly and the system was working at the desired level that cycle time values were to be around 4% to 15% better than 2300 rpm. When 2600 rpm comes, it is seen that the system works close to the upper limit values as pressure, flow rate and cycle time. Cycle time values were to be around 0.6% to 7% better than 2450 rpm. Although machine performance is the highest level, it has been observed that fuel consumption increases proportionally and the system is operating close to the limit values, which are not as suitable for operating modes as other cycles.

6. CONCLUSION

As a result of this thesis study, the powertrain group for the compact hydraulic excavator was examined and optimum operating modes were determined. When the test results were examined in detail, the average fuel consumption values in the operating modes of the machine were determined. Hydraulic pressure and flow rates were analyzed in these values. With all these findings, the cycle time values of the machine have been referenced to make the necessary comparisons in terms of operation performance. With data collected every second, more accurate data were collected for pressure, flow rate, fuel consumption values during operation. Tests have allowed the machine to obtain and compare hourly fuel consumption values instead of movement-based fuel consumption results. Thus, it offers more accurate results with regard to working efficiency. Providing instantaneous pressure, flow rate and fuel consumption values has allowed the machine to more clearly examine the responses to the work performed during the operation. When the cycle time values are examined in general, the values up to 2000 rpm are improved linearly, while the fuel consumption values increase at the same rate. However, when the test results are examined in 2450 rpm, 2600 engine speed, cycle time values are improved at a certain rate, while fuel consumption is increasing more. Therefore, efficiency in this section is lower than 2000 to 2450 rpm. Due to growth of compact hydraulic excavator market with day by day, efficient work in narrow spaces and regulations, the study to be done for the compact hydraulic excavator is expected to increase. Hereby, the results listed below for possible studies in next time may be considered as the benefits of this study:

- In the compact excavator, piston and gear hydraulic pumps offer performance graphs based on time of pressure and flow values in different operating cycles. In addition, it contains detailed information about the effect on fuel consumption.
- Hydraulic system design for compact excavators, the most important parameters to determine and apply hydraulic pressure and flow values.
- The effect of trench digging, straight travelling, soil levelling and standby idling on hydraulic system and fuel consumption in one-hour work.
- Cycle time data as measurement parameter for determining efficient working range for compact excavators.
- Instead of inducing operation-based assessments to compare efficiency and fuel consumption, the method of obtaining hourly fuel consumption values in real working conditions
- To determine operating modes according to actual operating conditions, to obtain system inputs and outputs and then to set operating modes (standard, power, eco etc.) to minimize excessive fuel consumption due to driver.
- The maximum operation limits for the hydraulic system (hydraulic pressure, hydraulic flow rate, cycle time, etc.) determination.

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CURRICULUM VITAE

İbrahim Saffa GÜNER graduated from B.S. in the Department of Automotive Engineering from the Cukurova University. After that, he started to MSc in the Department of Automotive Engineering from the Cukurova University. His research interests are investigation of earth-moving machinery design, powertrain applications, hyraulic and chassis subjects. He has work experience as a research and development design engineer in the MST Construction & Agriculture Machinery A.Ş.(2015-2018).