Palestine Polytechnic University

College of Engineering

Mechanical Engineering Department

Automotive Engineering

Graduation Project

The practical application of analyzing the exhaust manifold of various designs

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Hebron, Jun 2021

إهداء

إلى المعلم الاول ... الحبيب المصطفى صلى الله عليه وسلم ... إلى القلب الحنون التي كانت بجانبي بكل المراحل التي مضت ... من تلذذت بالمعاناة وكانت شمعة تحترق لتنير دربي ... إلى أمهاتنا الحبيبات.. إلى من علمني أن اقف وكيف ابدأ الالف ميل بخطوة .. إلى يدي اليمنى .. إلى من علمني الصعود وعيناه ترقباني ... إلى آبائنا الأجلاء .. إلى من رووني من ينابيع الفضيلة .. إلى الذين أخذو بيدي إلى منهل المعرفة وأظلوني بشجرة الإيمان ... إلى أهلنا الأعزاء.. إلى من أمسك بيدي وعلمني حرفا .. إلى من كانوا سندا لي ..

الى من لهم الفضل بإرشادي إلى طريق العلم والمعرفة ..

إلى الدكتور الفاضل حسين عمرو والدكتور الفاضل زهدي سلهب.

إلى جميع أساتذتي الكرام؛ ممن لم يتوانوا في مد يد العون لي

إلى كل محبي المعرفة.

إلى من ضاقت السطور عن ذكرهم فوسعهم قلبي ... إلى أصدقائنا الأوفياء.

إلى من ضحوا بحرياتهم من أجل حرية غيرهم ... إلى أسرانا البواسل.

إلى من هم أكرم منا ... إلى شهدائنا الأبرار.

ولن أنسى هذا المكان الذي جمعني بمقاعده وأبوابه حتى فنائه .. إلى كل جزء .. إلى جامعة بوليتكنك فلسطين إلى من احتضنتني طوال هذه الأعوام ... إلى فلسطين الحبيبة ..

نهدي علمنا هذا ..

Abstract

Reverse Engineering in terms of mechanical engineering is the process of extracting knowledge or design of information and re-producing it based on the extracted information. The process usually includes a 3D scanning of the object, transfer of the 3D scanned data to the computer for measurements, and data sensing, based on 3D high quality analysis. The created model using CAD is used in analyzing, modifying, optimizing, and manufacturing the desired object. This project is aimed to To produce a design identical to the design of the exhaust manifold that is being studied practically and to change some dimensions in order to raise the efficiency of the engine by reducing pressure and increasing the speed of exit of gases from the exhaust. The mechanical part of the exhaust manifold was obtained, and a three-dimensional model of the exhaust manifold was created by making a three-dimensional survey of it, and the three-dimensional image was entered into the Geomagic program to extract the practical model and then transferred the model to the CATIA program to change the dimensions and use a set of designs and dimensions in order to get the best Design, and extract the values of pressure, speed and temperature using the Ansys program

الملخص

الهندسة العكسية من حيث الهندسة الميكانيكية هي عملية استخراج المعرفة أو تصميم المعلومات وإعادة إنتاجها بناءً على المعلومات المستخرجة. تتضمن العملية عادةً مسحًا ثلاثي الأبعاد للكائن، ونقل البيانات الممسوحة ضوئيًا ثلاثي الأبعاد إلى ملف جهاز كمبيوتر للقياسات واستشعار البيانات، بناءً على تحليل ثلاثي الأبعاد عالي الجودة. يتم استخدام النموذج الذي تم إنشاؤه باستخدام CAD في تحليل وتعديل وتحسين وتصنيع الكائن المطلوب. يهدف هذا المشروع إلى إنتاج تصميم مطابق لتصميم مجمع العادم الذي تتم دراسته عملياً وتغيير بعض الأبعاد من أجل رفع كفاءة المحرك عن طريق تقليل الضغط وزيادة سرعة خروج الغازات من العادم تم الحصول على الجزء الميكانيكي لمشعب العادم، وتم إنشاء نموذج ثلاثي الأبعاد لمشعب العادم بإجراء مسح ثلاثي الأبعاد له، وتم إدخال الصورة ثلاثية الأبعاد في برنامج Geomagic لاستخراج النموذج العملي. ومن ثم نقل النموذج إلى برنامج CATIA لتغيير الأبعاد واستخدام مجموعة من التصاميم والأبعاد من أجل الحصول على أفضل تصميم، واستخراج قيم الضغط والسرعة ودرجة الحرارة باستخدام برنامج Ansys

Contents

List of Tables

List of Figures

List of Abbreviations, Symbols and Nomenclature

3D - Three-Dimensional
2D - Two-Dimensional
CAD - Computer Aided Design
CAx - Computer Aided Technologies
Φ - Pressure Angle
Ψ - Helix Angle
T - Motor Torque N.M
Pb - Motor Power (Engine Brake Power)
W - Power Is a Measure of Work Performance Rating
N - Engine Rotation Speed Rpm
Pm - Actual Mean Effective Pressure (N/M^2)
L - Length of Stroke (M)
A - Area of The Cross-Section of the Cylinder (M^2)
N - RPM of The Engine Crankshaft
I.P - Indicated Power
B.P - Break Power
Mf - Mass of Fuel Supplied (Kg/Sec)
Cv - Calorific Value of Fuel (J/Kg)
I.P - Indicated Power
P - Pressure
V - Temperature
T - Velocity
Ds - Pressure Force Analog To Isotropic Stress In Structural Mechanics
G - Gravity Force
E - The Total Energy Per Unit Volume
T - Temperature
k - Thermal Conductivity
U - Characteristic Velocity
L - Characteristic Length
V - The Kinematic Viscosity
K - Kelvin

1

Chapter One
Introduction

1.1 Introduction

1.2 spark-ignition engine

1.3 Project outlines

1.4 design and simulation of the exhaust manifold

1.5 Factors affecting engine power (Pb)

1.6 Factors affecting engine power are

1.7 Time Tables

1.1 Introduction

car or automobile was defined by the simplest terms as a wheeled motor vehicle used for transportation. The year 1886 was considered as the beginning of the modern car by Karl Benz who patented his Benz Patent-Motorwagen. Automobile Spreader globally during the 20th century.

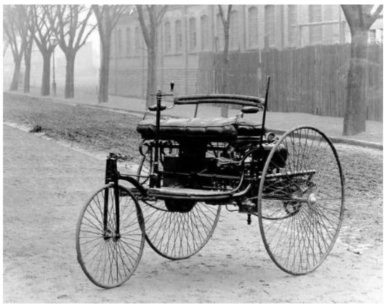

Figure 1.1 Benz Patent-Motorwagen

An internal combustion engine in which combustion of a fuel occurs in a combustion chamber in an internal combustion engine, the output energy thermal energy and high-pressure gases produced by combustion used directly by applying force on some component of the engine to be transformed to mechanical energy. The first modern internal combustion engine was created by Nicolaus Otto in 1876. four-stroke and two-stroke piston engines are examples of an internal combustion engine.

The fuels used in automobile engines vary, including gasoline, diesel, and natural gas. Other than electric cars, this research study includes a petrol engine. The essential difference between a gasoline engine and a diesel engine is the ignition method, as gasoline engines depend on the electric spark coming from the spark blogs for ignition, while diesel depends on the ignition on pressure without the need for a spark.

1.2 spark-ignition engine

spark-ignition engine (SI engine) The spark-ignition engine is(usually a gasoline engine), a four-cylinder engine, each cylinder has the Spark blog on it, the engine cycle consists of four strokes, the intake, pressure, ignition, and the exhaust. As will be explained briefly in chapter three.

Figure 1.2 Spark plug

1.3 Project outlines

Analyzing the exhaust manifold of different designs by Ansys and studying the effect of changing the design in the exhaust manifold using programs on engine performance.

Figure 1.3 Exhaust manifold

1.4 design and simulation of the exhaust manifold

This project used Catia Design Program to build the exhaust part and prepare it for the simulation of the exhaust manifold for a gasoline engine vehicle will be done by the ANSYS to analyses the change in engine performance resulting from the change in the design of the exhaust manifold, then the study will be practically applied through the cultivation of three sensors (temperature, pressure and, speed) Inside the exhaust manifold and studying its effect on engine performance.

1.5 Engine Power (Pb)

Motor power is the power output from the motor output shaft (crankshaft). The value of the engine's power is determined by measuring it by braking at a full-throttle opening (full load) and it is called the brake power of the engine. There are many units used to measure engine power such as kilowatt or horsepower

Power is known as the product of torque times rotational velocity

$$Pb = T.W = T\frac{2*Pi*N}{60}$$ .... Equation1.1 engine power (Pb)

The effect of exhaust manifold on the engine power is mainly affected by the amount of air flow leaving combustion chamber

1.6 Factors that affecting engine power

1. Indicated Power

It depends on the type of thermal cycle (gasoline, diesel, ...), compression ratio, mechanical efficiency.

$$I.P = \frac{Pm*L*A*N}{60000*2} KW$$ .... Equation1.2 Indicated Power

2. Mechanical efficiency

Dependent on friction and loss to drive rings, the mechanical efficiency decreases at partial loads of the motor (equal to zero at the empty load). Between 80-90% for combustion engines.

$$\eta mech = \frac{B.P}{I.P}$$ .... Equation1.3 Mechanical efficiency

3. Thermal Efficiency

It depends on the thermal cycle type: Gasoline engines (25-35%) and diesel engines 45%.

$$\eta it = \frac{I.P}{mf*C.V}$$ .... Equation1.4 Thermal Efficiency

4. Fuel Mass Rate

It depends on thermal efficiency, fuel type, and operating conditions.

5. Fuel Calorific value

It is stable concerning gasoline and diesel and ranges between 4200-4400 kJ / kg.

6. Air Mass Rate

It depends on the incoming air volume and air density.

7. Fuel-Air Ratio

It is based on a ratio of (f / e) 0.07 for the best combustion and exhaust gases.

8. Air Density

It depends on the temperature of the charge.

9. Air Flow Rate

Cylinder section area, piston speed, valve timing depends on the cross-sectional area and airflow velocity.

10. Volumetric Efficiency

depends on engine design and the following operating parameters: mixture temperature-ratio between intake and exhaust pressure - compression ratio - engine speed - design of intake and exhaust manifolds. A value between 70-80% for engines and more than 100% for charged engines. Forced charging and valve timing.

$$\eta vol = \frac{Actual\ volume\ of\ charge}{-air\ sucked\ at\ atm\ .condition\ Swept\ volume} \ldots\ldots\text{. Equation1.5 Volumetric Efficiency}$$

11. Engine Swept Volume

It depends on the design and dimensions of the engine.

12. Engine Speed

Specific to the maximum value of inertia forces, engine throttle for gasoline engines.

13. The Number of Storks

A two-stroke engine of the same dimensions is theoretically twice as powerful as a four-stroke engine.

14. Compression Ratio

Dependent on engine design, defined by slapping limit for petrol engines - stress limit for diesel.

15. Engine Dimensions

Depends on engine design, engine capacity, power, and torque required.

The change in the exhaust manifold affects heat distribution, back pressure and air flow which are directly related to these 15 variables

1.7 Time Tables

	1st semester															
Task/week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Project Selection	■	■	■													
Collection Information				■	■	■	■									
Literature Review							■	■								
Learning CATIA Software						■	■	■	■	■	■	■	■			
Drawing Part									■	■	■	■	■	■		
Learning Ansys Software								■	■	■	■	■	■	■	■	
Documentation														■	■	■

Table1.1 First Semester Time Table

	2nd semester															
Task/week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
preparing mechanical part	■	■	■													
Learning 3D scanning				■	■	■										
Scanning exhaust manifold					■	■	■									
Installation of sensors & Practical data recording								■	■	■	■	■	■			
Preparing Scanning Data by Geomagic in a Required Shape										■	■	■	■	■	■	
Writing the Text								■	■	■	■	■	■	■	■	
comparing The actual Result															■	■
Make the Final Adjustments													■	■	■	■

Table1.2 Second Semester Time Table

2

Chapter Two
Work process

2.1 Objectives

2.2 Project explain

2.3 Exhaust Manifold Design

2.4 3D-scanning

2.5 Geomagic Design

2.6 Design Programs

2.1 Objectives

1. Studying the effect of changing exhaust manifold design on the exhaust gas such as :
    1. Temperature
    2. Pressure
    3. Velocity inside the exhaust manifold
2. Applying modification at the original manifold design by Ansys to reach the most efficient design from the designs experiments that done for this study

2.2 Project explain

In this project, the design will be modified for the exhaust manifold, to try to raise the efficiency of the engine, as we have made work 3D-Scanning for the exhaust manifold and return the design to the programs Engineering to modify this design. by engineering programs (Catia and Ansys) to obtain the best results in the influencing factors P.V.T (pressure, temperature, velocity).

In the practical part, when obtaining the best results from the modification of the exhaust manifold using the software, casting this design and install it on a vehicle after sensors implants of the factors affecting it, and take data from sensors to compare it with the results of the design programs.
And then taking read life data (car information while engine running) of the vehicle after installing the new design on it and comparing it with the readings life data before modifying it, and the extent of its impact on the efficiency of the engine and the vehicle in general.

The best result that can be obtained by modifying the exhaust ducts is to reduce the back pressure on the cylinders, and this leads to increased combustion efficiency and as a result, increased engine efficiency and reduced fuel consumption.

2.3 Exhaust Manifold Design

The exhaust manifold is the first part of the vehicle exhaust system. It is connected to the vehicle engine and collects the engine emissions. The exhaust manifold receives the(air/fuel) mixture from the multiple cylinders in the vehicle engine. It collects the fuel/air mixture from each cylinder, not only does the exhaust manifold receive all of the burnt engine gases, but also it completely burns any unused or incomplete burnt gases using its very high temperature.

The design of the exhaust manifold is one of the most important parts that can be controlled in order to obtain a higher engine efficiency by controlling the pipe lengths, where sharp corners are among the causes that create back pressure on the engine, and smooth corners must be taken into account to achieve the best flow of exhaust gases when leaving the engine

2.4 3D-scanning

3D-scanning was mainly used to obtain the measurements for the exhaust manifold using reverse engineering technology, as this technology was relied upon because it extracts the exact dimensions in the part with high accuracy and at a convenient time compared to the designing from scratch. There are different types of technologies for digitally acquiring the shape of a 3D object.

In this study, a 3D scan was used instead of the online models for the exhaust manifold of this study due to the presence of a practical application in order to obtain the greatest possible accuracy.

The techniques work with most or all sensor types including optical, acoustic, laser scanning, radar, and thermal.

A well-established classification divides them into different types such as the used technology in this study:

Hand-held laser scanners create a 3D image through laser dots or line is projected onto an object from a hand-held device and a sensor measures the distance to the surface. Data is collected in relation to an internal coordinate system and therefore to collect data where the scanner is in motion the position of the scanner must be determined.

Data is collected by a computer and recorded as data points within three-dimensional space, with processing this can be converted into a triangulated mesh and then a computer-aided design model, often as non-uniform rational B-spline surfaces.

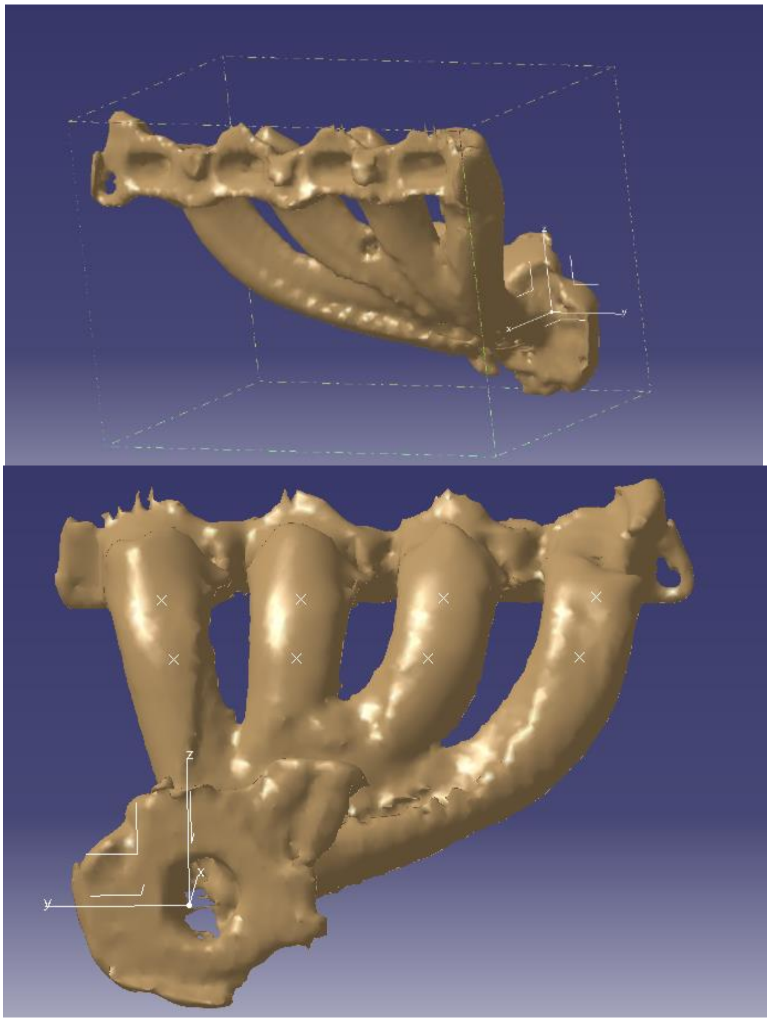

Figure 2.1 3D image

The Next Engine Scanner is a desktop 3D scanner that uses an array of lasers to scan objects at resolutions of 0.005 inches.
One of its uses in industry is for reverse-engineering scan for different components, and reassemble them in CAD software like SolidWorks or Catia.

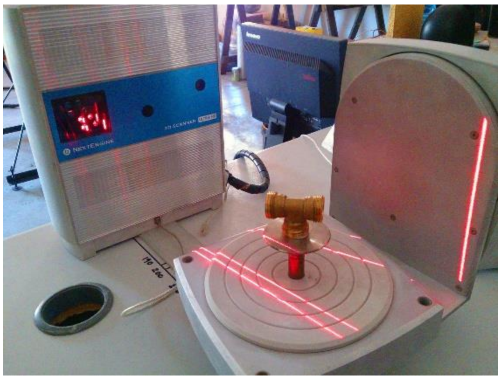

Figure 2.2 Next Engine Scanner

Once the scanning done, then will used Geomagic Studio software to trim the parts of the scan will not have needed to use it in Catia.

2.5 Geomagic Design

Introduction Geomagic Design there are unique features that this program owned as well explained:
Geomagic is a Powerful and Flexible program is purpose-built for converting 3D scan data into high-quality feature-based CAD models. It does what no other software can with its combination of automatic and guided solid model extraction, incredibly accurate exact surface fitting to organic 3D scans, mesh editing and point cloud processing.
And the main reason to use Geomagic is that the program can Work Seamlessly with Your Existing CAD programs mainly for CAD programs like Catia, using unique Live Transfer technology, Design X transfers complete models, including feature trees, so you can quickly create solid and surface models from 3D scans.

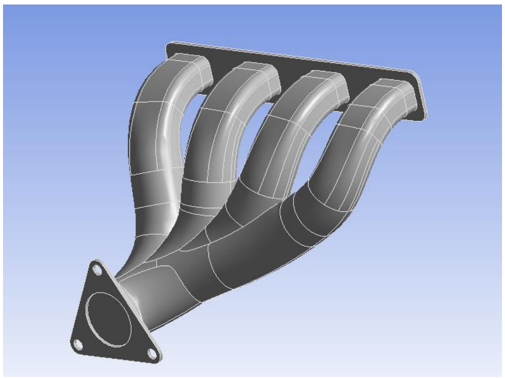

Figure 2.3 Geomagic Design

2.6 Design Programs

The project depends on several programs, the most important programs that we used, design program and simulation programs, in this part we will identify the programs.

2.6.1 Catia

2.6.1.1 Introduction

It is used to design, simulate, analyses, and manufacture products in a variety of industries including aerospace, automotive, consumer goods, and industrial machinery, just to name a few. It addresses all manufacturing organizations, from OEMs through their supply chains, to small independent producers.

2.6.1.2 Why CATIA

In this project, CATIA V5was used to develop 3D CAD model for exhaust manifold dimensions and curves, CATIA has important modules such as generative shape design. This program was choosing to work on over Ansys program to get the needed results, it is easy to make combined curves for the involute exhaust pipes. CATIA does not need computers with high specification to run.

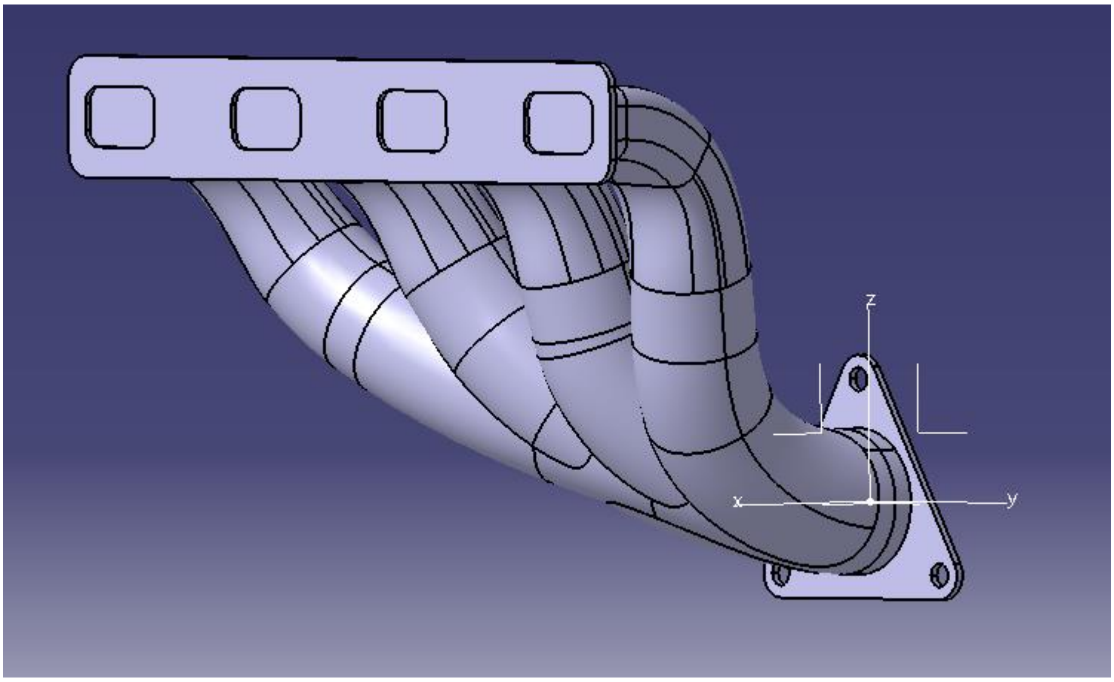

Figure 2.4 Design in Catia program

2.6.2 Ansys

Engineering Simulation Software. Ansys Mechanical finite element analysis software is used to simulate computer models of structures, electronics, or machine components for analyzing strength, toughness, elasticity, temperature distribution, electromagnetism, fluid flow, and other attributes where Ansys used to simulate the manifold to understand exhaust gases (fluid) behavior using CFD and partial differential equations PDE to make a full simulation for the designed parts.

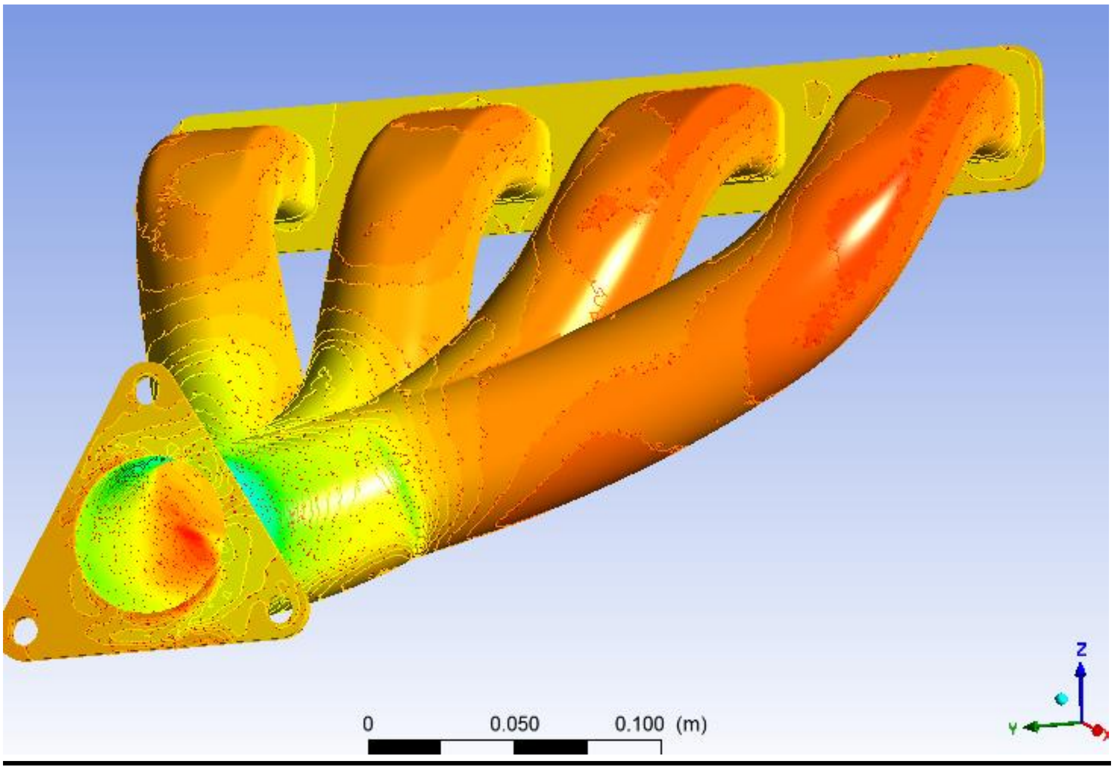

Figure 2.5 Design in Ansys program

3

Chapter Three
Fluids

3.1 Fluid

3.2 Engine work

3.3 Change Design

3.4 Computational Fluid Dynamics (CFD)

3.5 Naiver–Stokes's equations

3. 6 Newtonian fluid

3.7 Turbulence and Reynolds number

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3.1 Fluid

fluids: any fluid that moves within the volume (such as a liquid or gas) that tends to flow and take the shape of its container.

In the case of internal combustion engines, the fluid that it deals with in the ignition process is the mixture of air, then as a result of composition, it becomes as exhaust gas resulting from the combustion process, where the burning fluid mixture of air and fuel flows through the exhaust ducts under certain pressure and temperature resulting from the exhaust gas as a result of combustion and the decrease in volume inside the cylinder in the exhaust stroke.

Air is known to be one of the compressible fluids and in the case of air compression in a fixed volume, it will cause increasing the temperature to the air and with adding fuel, in a certain stage, it then explodes, which increases the pressure and temperature at parts from second to high degrees.

3.2 Engine work

The engine has four-strokes:

- intake stroke where the engine suctions the air from the intake manifold when the piston moves from the top dead center to the bottom dead center
- Compression stroke where the piston moves from the bottom dead center to the top dead center the air compressed at a constant temperature at variable volume, then at the end of this stroke the injector injects fuel that increases the pressure even more then at that moment the ignite come from the spark plug to start the flaming of the mixture.
- combustion stroke the piston moves from the top dead center to the bottom dead center at a very high velocity at the end of this stroke the exhaust gas valve open to allow the exhaust gas to go out.
- The air then in the exhaust stroke exit the combusted air and fuel mixture to the exhaust manifold as the volume is fixed in the exhaust manifold and as a result, Due to the presence of the body of the exhaust manifold and as a result

of air friction with the inner walls of the manifold, this works to direct the air to the desired path, and in that event, there are angles or bends in the exhaust manifold, This works on creating vortices inside the manifold, which causes a change in the velocities of the airflow inside the manifold and the way the air exits, and in the case of strong vortices and angles, these waves may work to distract the flow of the fluid and this works to create a back-pressure or impedance to the movement of the fluid. Where the studied design is based on searching for the best interior angles so that the airflow velocity is balanced with the vortices that affect the formation of the reverse pressure.

3.3 Change Design

The design will have Modification at the length of exhaust manifold ducts, which increase the gases velocity reduces the formation of these districts vortices and this helps to reduce the back-pressure on the cylinders, which facilitates the exit of gas and this reflects the reduction of pressure on the cylinders and this means increasing the utilization of the power coming out of the engine because the design reduces the power used to extract gas from cylinders.

The design to be modified will expert also that adjust the thickness of the walls of the exhaust manifold, either by increasing or decreasing the thickness, which increases the heat transfer and improves the heat exchange between the body of the exhaust manifold and the outside air in contact with it.

3.4 Computational Fluid Dynamics (CFD)

Computational Fluid Dynamics (CFD) is the description of these partial differential equations (PDE) and solving them using computers.
Fluid mechanics deals with the motion of fluids (liquids and gases), induced by external forces.

Fluid flow is modeled by partial differential equations (PDE), describing the conservation of mass, momentum, and energy.

CFD used as pre-design of components: simulation vs. experiment in Aerospace and aeronautical applications, Mechanical applications (gas turbines, heat exchange, explosions, combustion, architecture), Biological applications (blood flow, breathing, drinking), and Meteorological applications (weather prediction).

3.5 Naiver–Stokes equations.

The governing equations of fluid dynamics are the conservation laws of mass, momentum, and energy.

In CFD, this set of conservation laws are called the Naiver–Stokes equations.

The equation that Naiver–Stokes depends on:

$$\frac{\mathrm{D}\mathcal{M}}{\mathrm{D}t} = \frac{\mathrm{D}}{\mathrm{D}t} \underbrace{\int_{\Omega(t)} \rho \, d\Omega}_{\mathcal{M}} = 0$$

...Equation 3.1 conservation of mass.

using the Reynolds transport theorem:

$$\boxed{\text{rate of mass change in } \Omega} + \boxed{\text{mass flow over } \partial\Omega} = 0,$$
$$\int_{\Omega} \frac{\partial \rho}{\partial t} \, d\Omega + \int_{\partial\Omega} \rho \mathbf{u} \cdot \mathbf{n} \, ds = 0.$$

Equation 3.2 conservation of mass by using the Reynolds transport theorem

The momentum equation describes the conservation of momentum.

$$\frac{\mathrm{Dm}}{\mathrm{D}t} = \frac{\mathrm{D}}{\mathrm{D}t}\int_{\Omega(t)} \rho\mathbf{u}\,d\Omega = \mathbf{K},$$

……… Equation 3.3 conservation of mass

$$\begin{aligned}&\boxed{\text{rate of momentum change in } \Omega} + \boxed{\text{momentum flow over } \partial\Omega}\\ &\quad = \boxed{\text{surface forces on } \partial\Omega} + \boxed{\text{volume forces on } \Omega},\end{aligned}$$

$$\int_{\Omega} \frac{\partial\rho\mathbf{u}}{\partial t}\,dV + \int_{\partial\Omega} \rho(\mathbf{u}\otimes\mathbf{u})\cdot\mathbf{n}\,ds = \underbrace{-\int_{\partial\Omega} p\mathbf{n}\,ds + \int_{\partial\Omega} \tau\cdot\mathbf{n}\,ds}_{\text{surface forces}} + \int_{\Omega} \rho\mathbf{f}\,d\Omega.$$

Equation 3.4 Decompose force into surface forces and volume forces

3. 6 Newtonian fluid

The model that relates the stress tensor to the velocity u:

We consider so-called Newtonian fluids, where the viscous stress is linearly related to strain rate, that is,

$$\tau = 2\mu\varepsilon(\mathbf{u}) - \frac{2}{3}\mu\mathbf{I}\,\mathrm{tr}\,\varepsilon(\mathbf{u}) = \mu\left(\nabla\mathbf{u} + (\nabla\mathbf{u})^T\right) - \frac{2}{3}\mu(\nabla\cdot\mathbf{u})\mathbf{I},$$

Equation 3.5 Newtonian fluids

The dynamic viscosity is assumed constant

$$\mu = \mu(T, p) \approx \text{constant}.$$

……. Equation 3.6 The dynamic viscosity

The energy equation describes the conservation of energy.

$$\frac{D\mathcal{E}}{Dt} = \frac{D}{Dt}\int_{\Omega(t)} \rho E\,d\Omega = \mathcal{L} + W$$

Equation 3.7 conservation of energy

Rewritten for a stationary control volume, explicitly specifying the source terms:

$$\boxed{\text{Rate of total energy change in } \Omega} + \boxed{\text{Total energy flow over } \partial\Omega} =$$
$$\boxed{\text{Rate of work of pressure and viscous forces on } \partial\Omega} +$$
$$\boxed{\text{Rate of work of forces on } \Omega} + \boxed{\text{Rate of heat added over } \partial\Omega}$$

$$\begin{aligned}\int_{\Omega} \frac{\partial \rho E}{\partial t}\, d\Omega + \int_{\partial\Omega} \rho E \mathbf{u} \cdot \mathbf{n}\, ds = - \int_{\partial\Omega} p\mathbf{u} \cdot \mathbf{n}\, ds + \int_{\partial\Omega} (\tau \cdot \mathbf{u}) \cdot \mathbf{n}\, ds \\ + \int_{\Omega} \rho \mathbf{f} \cdot \mathbf{u}\, d\Omega + \int_{\partial\Omega} k \nabla T \cdot \mathbf{n}\, ds\end{aligned}$$

Equation 3.8 conservation of energy stationary control volume

The compressible Navier–Stokes equations in integral form:

The equations of continuity, momentum, and energy can be combined into one system of equations.

Define compound variable U = (ρ; ρu1; ρu2; ρu3; ρE) (called conservative variables)

Define flux vectors:

$$\mathcal{F} \cdot \mathbf{n} = \underbrace{\begin{bmatrix} \rho \mathbf{u} \cdot \mathbf{n} \\ \rho(\mathbf{u} \otimes \mathbf{u}) \cdot \mathbf{n} + p\mathbf{I} \cdot \mathbf{n} \\ (\rho E + p)\mathbf{u} \cdot \mathbf{n} \end{bmatrix}}_{\text{inviscid/convective}} - \underbrace{\begin{bmatrix} 0 \\ \tau \cdot \mathbf{n} \\ (\tau \cdot \mathbf{u}) \cdot \mathbf{n} + k(\nabla T) \cdot \mathbf{n} \end{bmatrix}}_{\text{viscous}}$$

Equation 3.9 Navier–Stokes equations in integral form

Compressible Navier–Stokes equations in integral form:

$$\int_{\Omega} \frac{\partial \mathbf{U}}{\partial t}\, d\Omega + \int_{\partial\Omega} \mathcal{F} \cdot \mathbf{n}\, ds = \int_{\Omega} \rho \mathbf{F}_e\, d\Omega$$

Equation 3.10 Navier–Stokes equations in integral form

Compressible Navier–Stokes equations, differential form by Apply the Gauss theorem to the integral form and get:

$$\int_{\Omega}\left(\frac{\partial \mathbf{U}}{\partial t}+\nabla\cdot\mathcal{F}-\rho\mathbf{F}_e\right)\,d\Omega=0.$$

Equation 3.11 Navier–Stokes equations in differential form

Since the integral is zero for an arbitrary control volume, we obtain the differential form of the Compressible Navier–Stokes equations:

Compressible Navier–Stokes equations

$$\frac{\partial \mathbf{U}}{\partial t}+\nabla\cdot\mathcal{F}=\rho\mathbf{F}_e.$$

Equation 3.12 Navier–Stokes equations in the differential form with integral are zero.

3.7 Turbulence and Reynolds number

3.7.1 Reynolds number

The Reynolds number is defined as:

$$\mathrm{Re}=\frac{UL}{\nu}=\frac{\text{Inertial forces}}{\text{Viscous forces}},$$

…Equation 3.13 Reynolds number

Fluids with the same Reynolds number behave the same way.

When the Reynolds number becomes larger than a critical value, the formerly laminar flow changes into turbulent flow, for example at Re ≈ 2300 for pipe flows.

3.7.2 Turbulence

Characteristic of turbulence flows are:

- time-dependent
- three dimensional
- Irregular
- vortical

The effect of the turbulence on the engine’s performance is a main factor, as it must be balanced to reach the best value without strong turbulence that creates a reverse pressure that prevents the exit of exhaust gases or that the movement of gas is laminar, which negatively affects the exit of exhaust gases.

4

Chapter Four
Design Process

4.1 Drawing by Using CATIA for an Object

4.2 Ansys

4.1 Drawing by Using CATIA for an Object

In the design, the dimensions taken from the Geo Magic program were used, which is based on the main dimensions of the original exhaust manifold.

so that the dimensions are identical to the practical design to compare the results obtained from the Ansys program with the values obtained from the sensors that were implanted in the exhaust manifold practically.

When opening CATIA program the interface which shown in Figure 4.1 will open, Generative shape design will be the main program for exhaust design and curves changing.

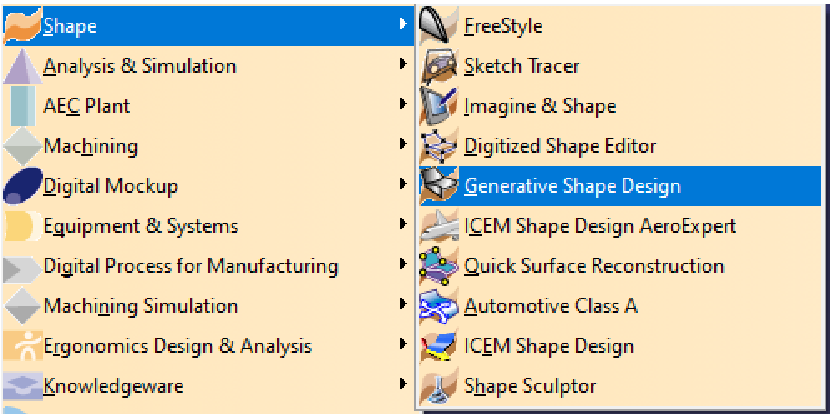


Figure 4.1 CATIA starting panale

- On the 2D plane sketching the shape of the manifold

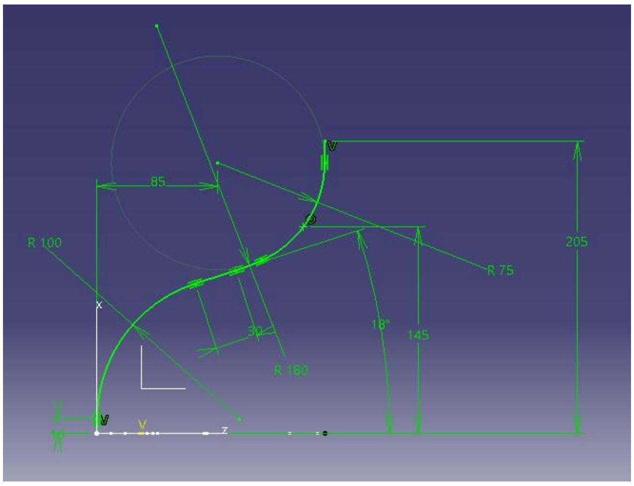


Figure 4.2 XZ Shape of the manifold in 2D

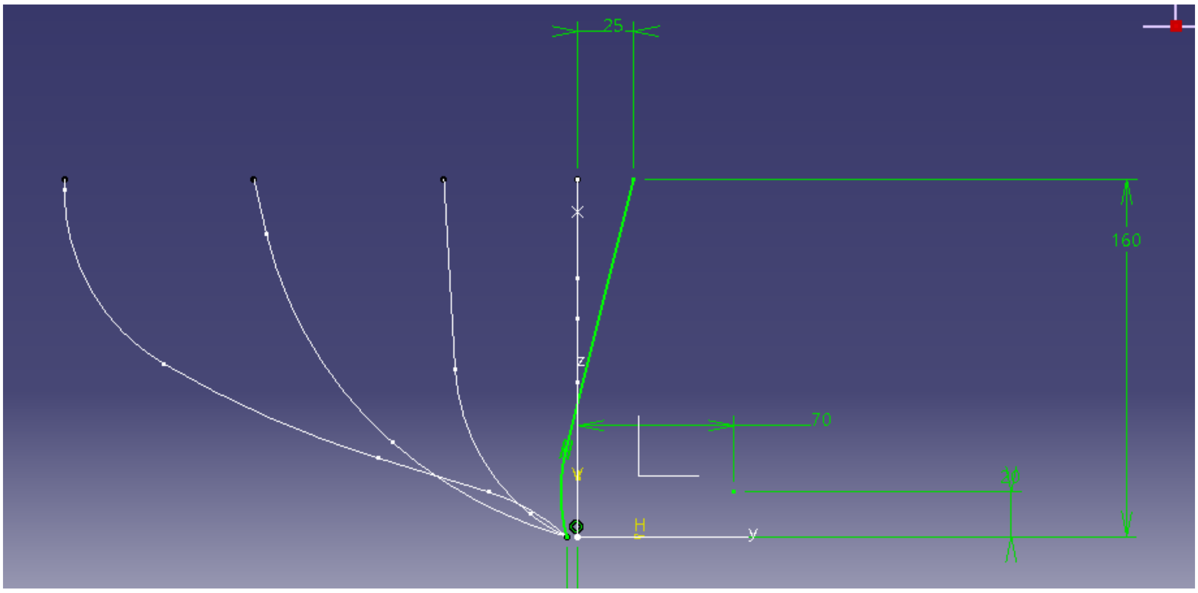


Figure 4.3 ZY Shape of the manifold in 2D

- By combining the first sketches with the four sketches then have curves as in figure 4.4

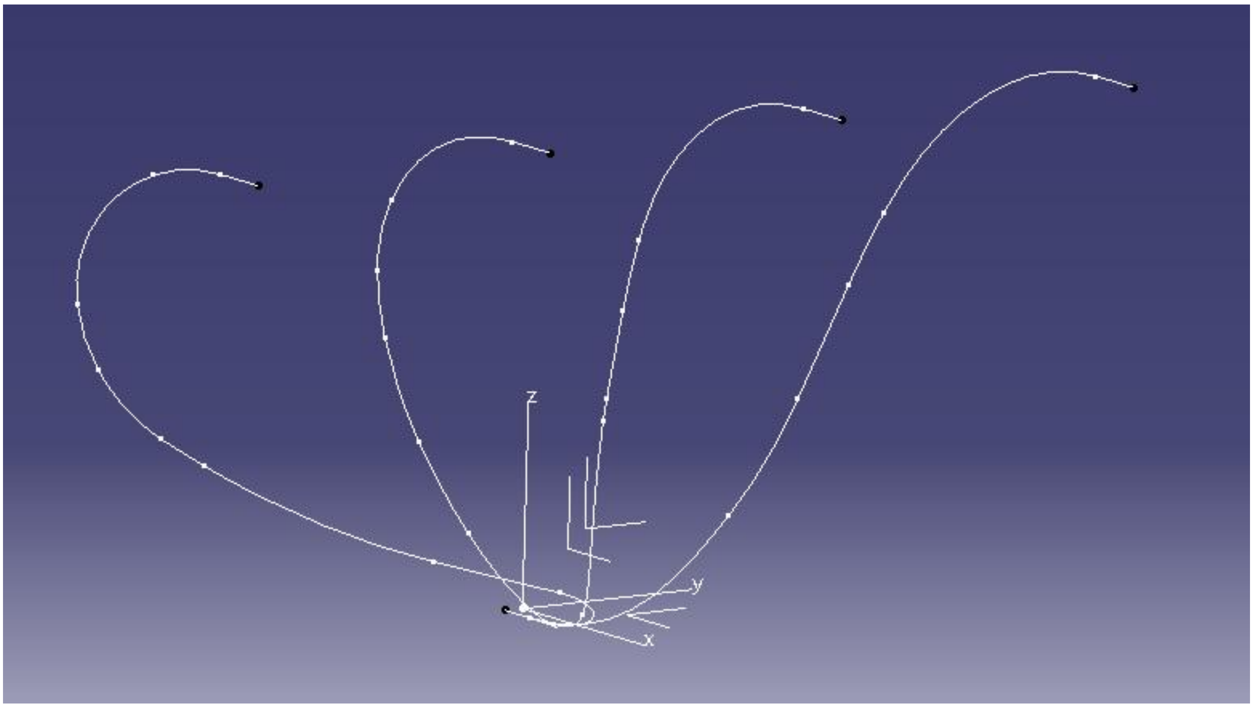


Figure 4.4 Combine the five 2D sketches

- Using the 2D sketch as the outer shape of the manifold inlet and Repeat it using rectangular pattern as in Figure 4.5

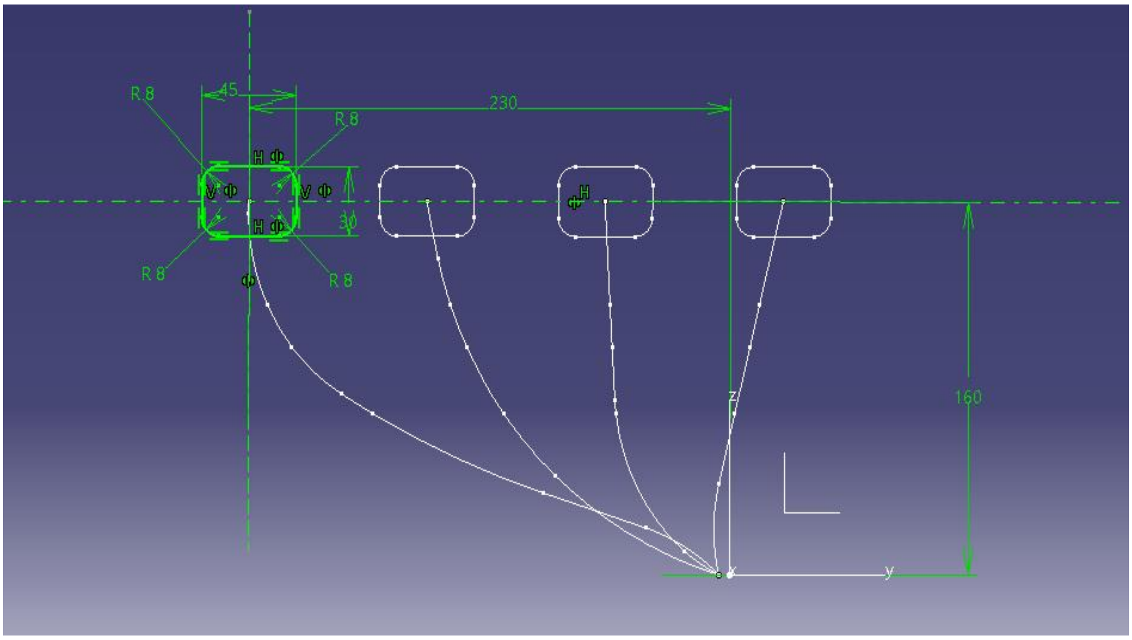


Figure 4.5 outer shape of the manifold inlet

- By using sweep then drawing the inlet pattern as in figure 4.6

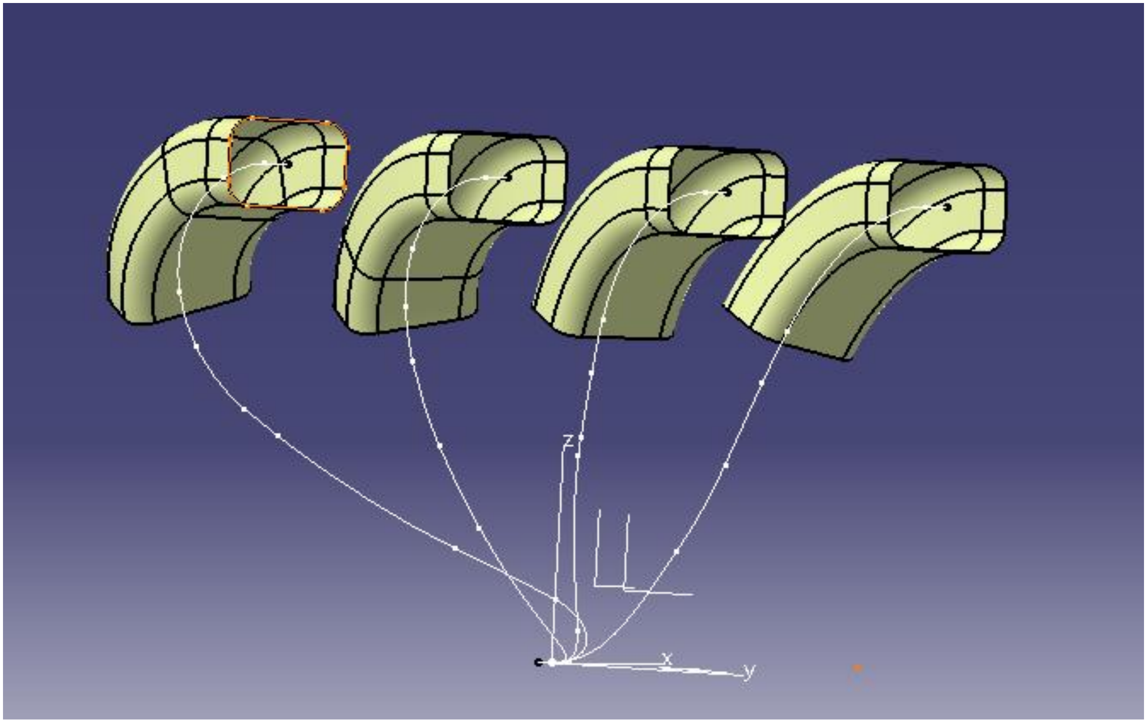


Figure 4.6 sweep inlet

- By using circular law sweep then drawing the outlet pattern as in figure 4.7

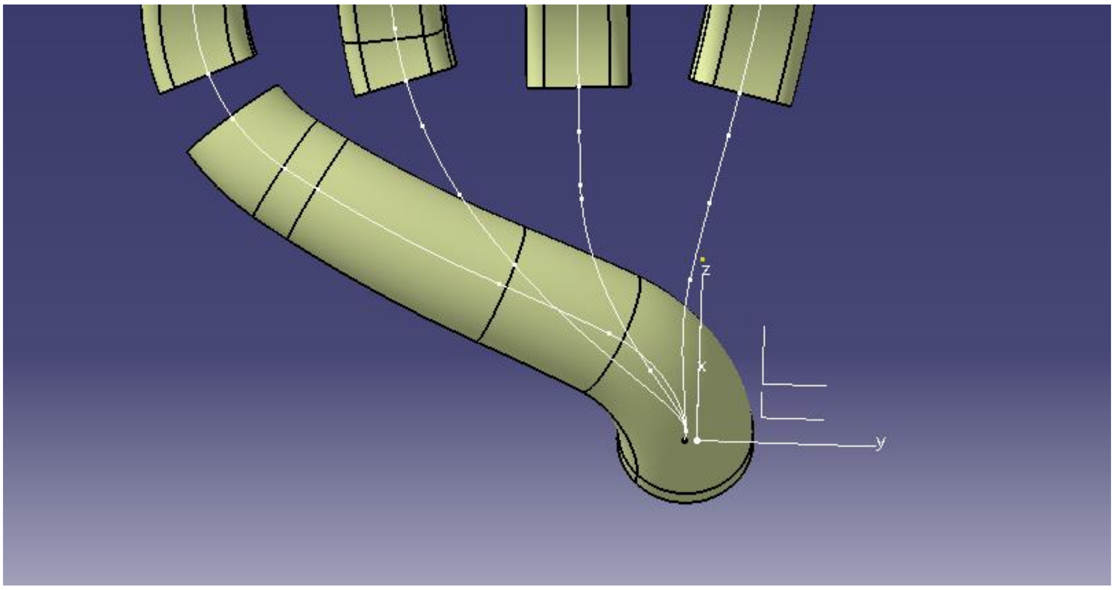


Figure 4.7 circular sweep for outlet

- By using Multi section surface connecting the inlet pattern in figure 4.6 with outlet pattern in figure 4.7 as is explained in figure 4.8

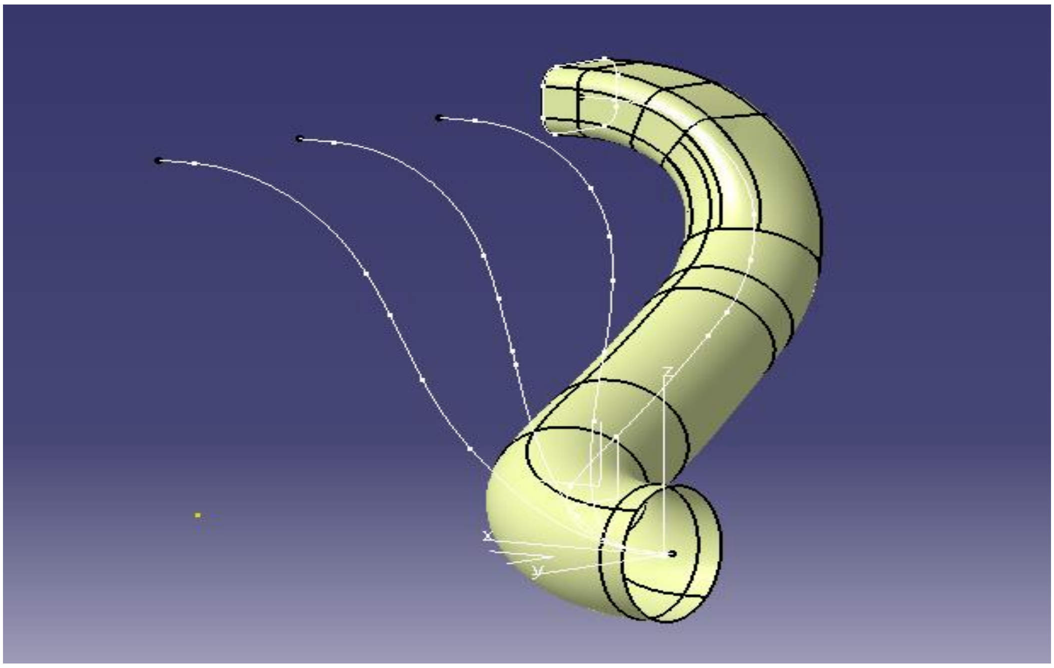


Figure 4.8 Multi section surface

- By sketch another 2D sketch to be the surface that will be in contact with the engine head as in figure 4.9

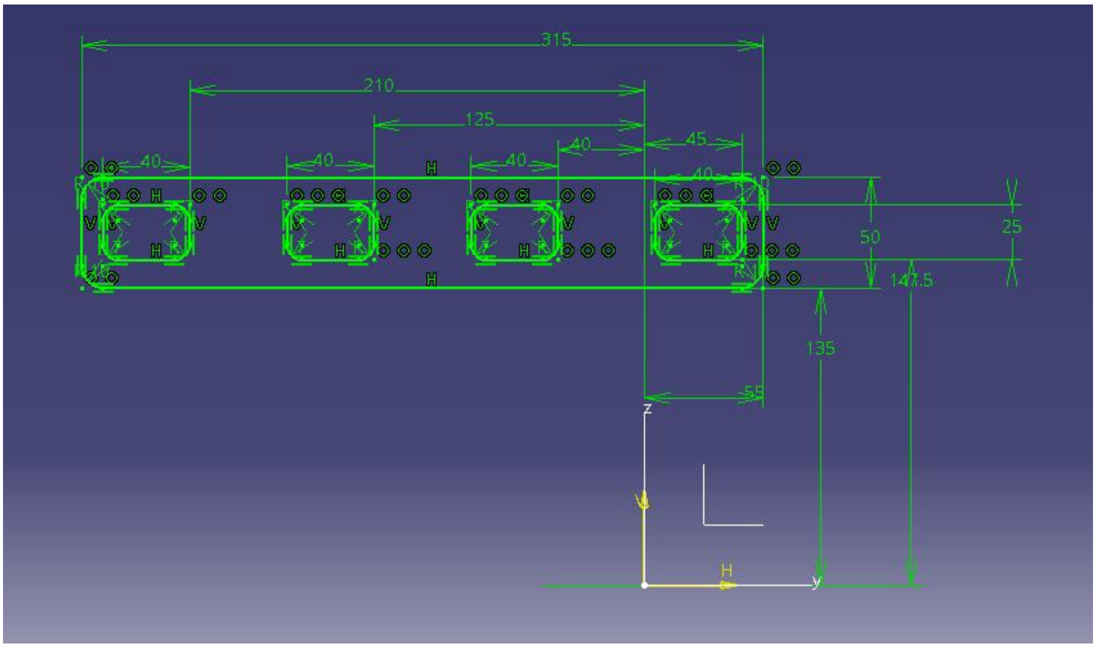


Figure 4.9 2D sketch for the contact surface

- By padding the sketch for design will become as in figure 4.10

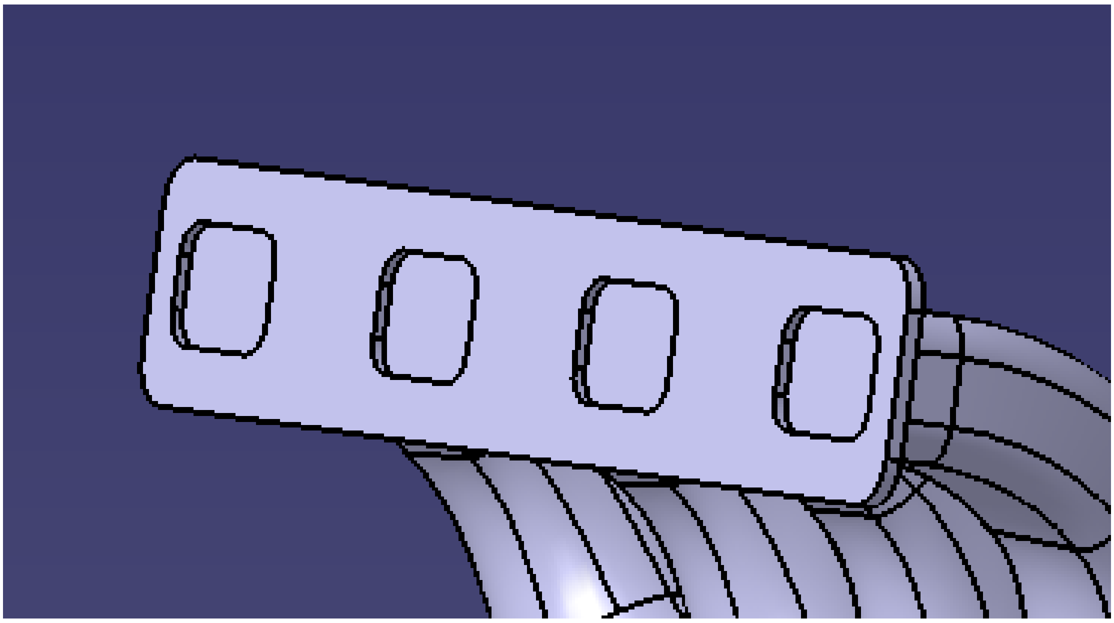


Figure 4.10 padding

- Then to the outlet of the exhaust manifold connection with the other parts sketching and padding it as in figure 4.11

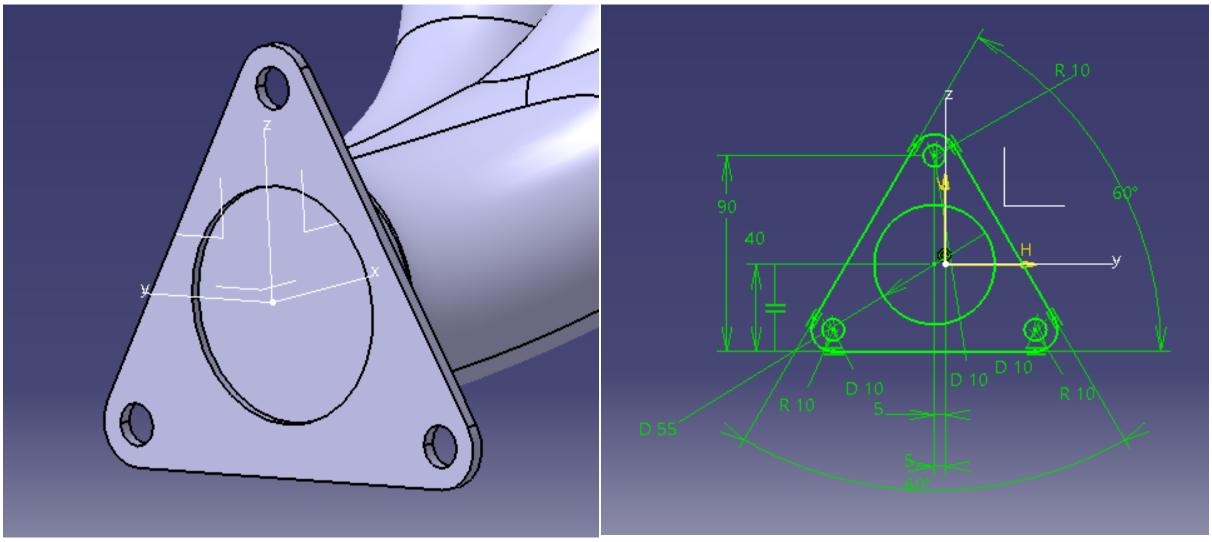


Figure 4.11 outlet of the exhaust manifold connection

- By using Close Surface on the completed tubes, the all design will become as in figure 4.12

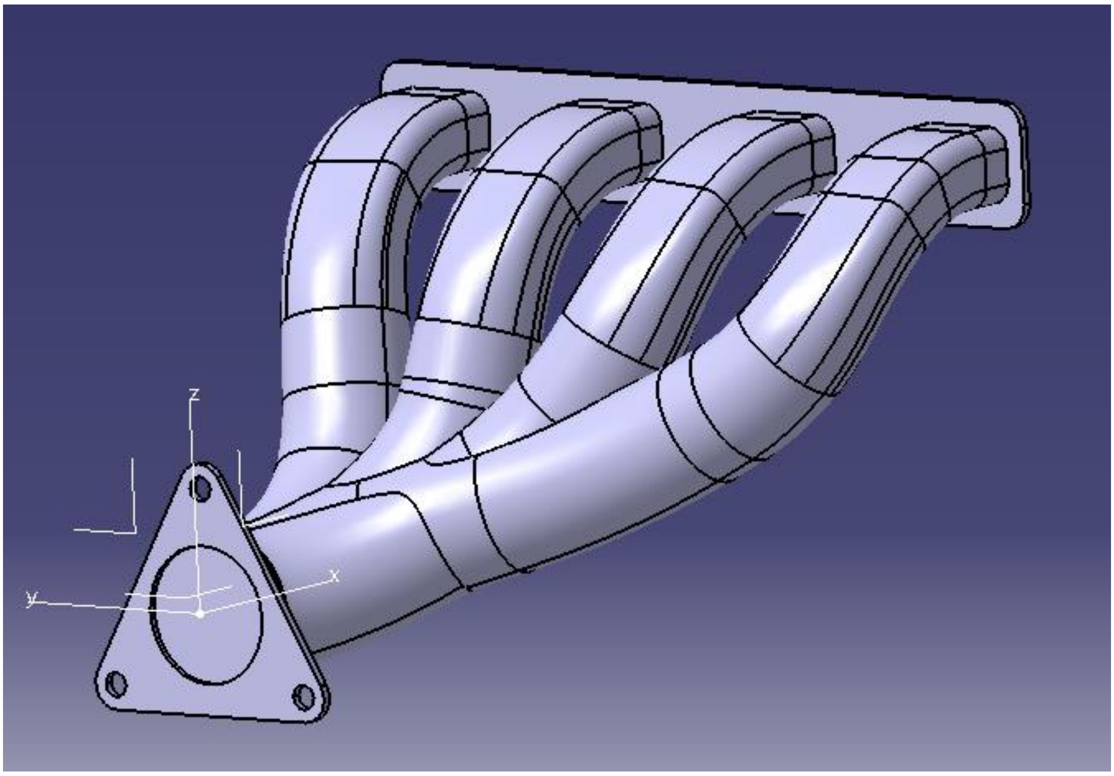


Figure 4.12 Close Surface step

- After all these design processes the design will go to the simulation program as (STP) file.

In this project, the best choice that allows all the results and characteristics to happen is using Ansys Program

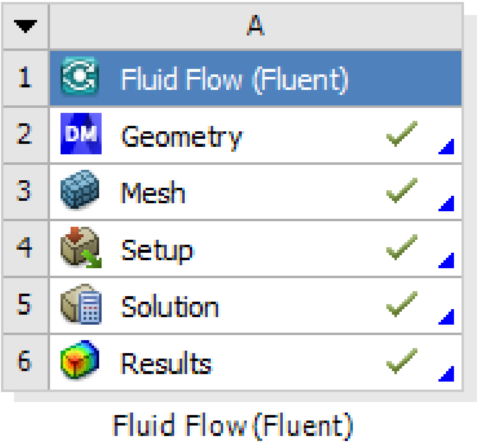
4.2 Ansys

For this design, Ansys was used for its ability to include the variables that were worked on, such as: describing the fluid conductance and heat distribution to make a complete simulation of the designed part.

The material chosen for this part in the Ansys program is steel due to the desire to match the reality as much as possible to reduce the error and divergence in the readings. The Cast Iron is used in the exhaust manifold due to its ability to withstand the high temperature and pressure that the exhaust manifold is subjected to.

In this project just Fluid Flow is used

In fluid flow by using design modular and importing Catia Design (STP) File as the geometry model of the manifold in the design modular section.

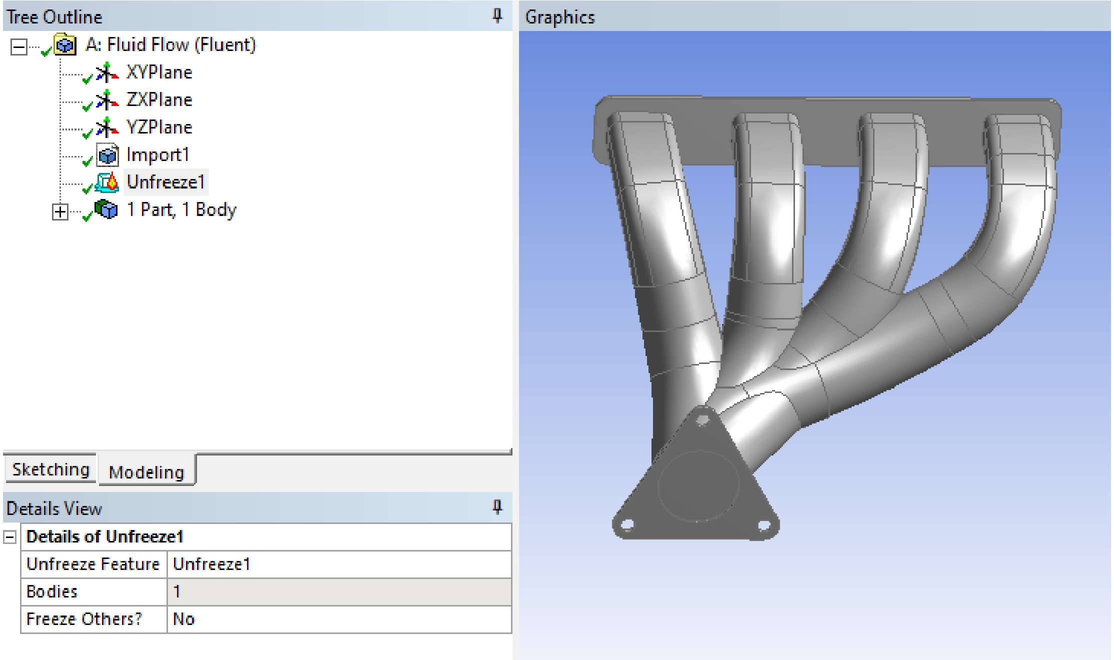


▼	A		
1	Fluid Flow (Fluent)		
2	Geometry	✓	◢
3	Mesh	✓	◢
4	Setup	✓	◢
5	Solution	✓	◢
6	Results	✓	◢

Fluid Flow (Fluent)

Figure 4.13 fluid flow program panel

- First, by unfreezing the part body it shows as a solid part in figure 4.14



Details of Unfreeze1	
Unfreeze Feature	Unfreeze1
Bodies	1
Freeze Others?	No

Figure 4.14 Unfreeze part

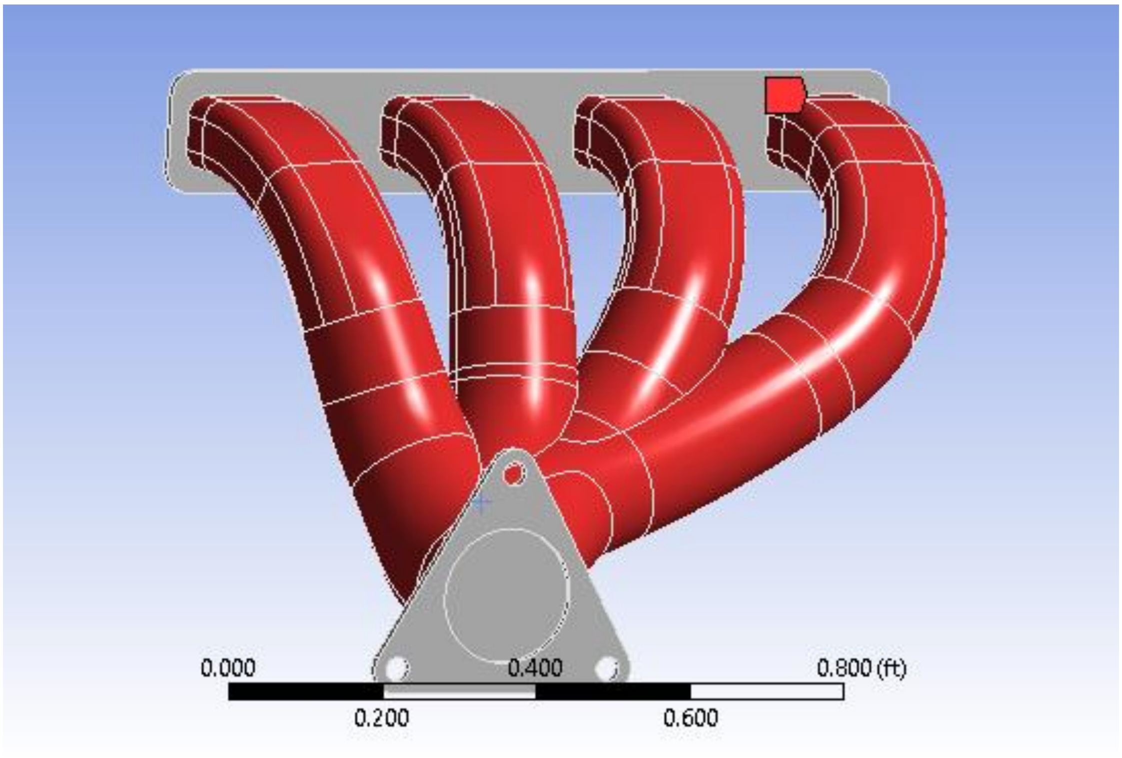


Figure 4.15 Body

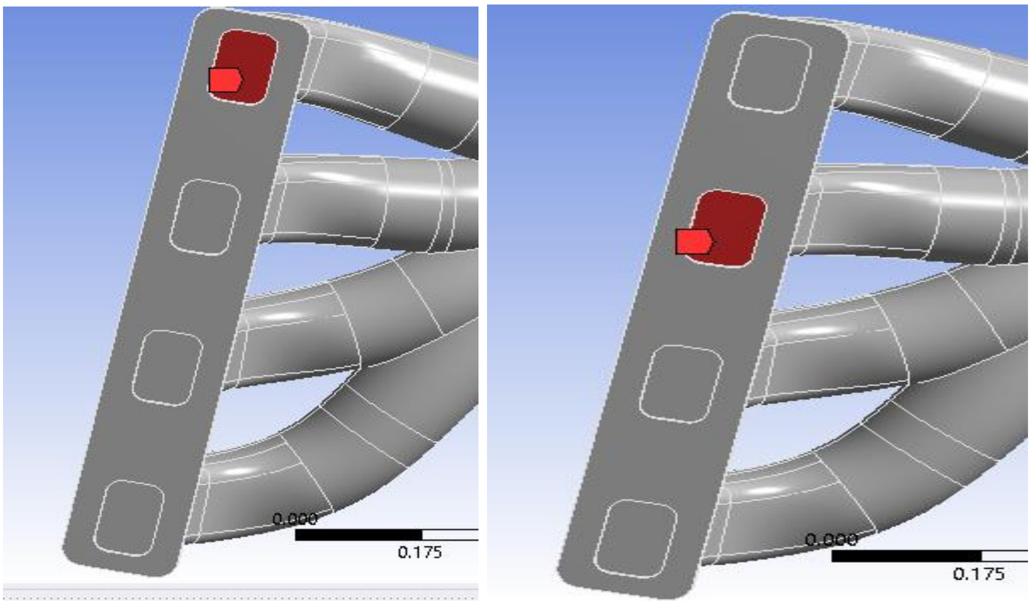


Figure 4.16.1 In-1

Figure 4.16.2 In-2

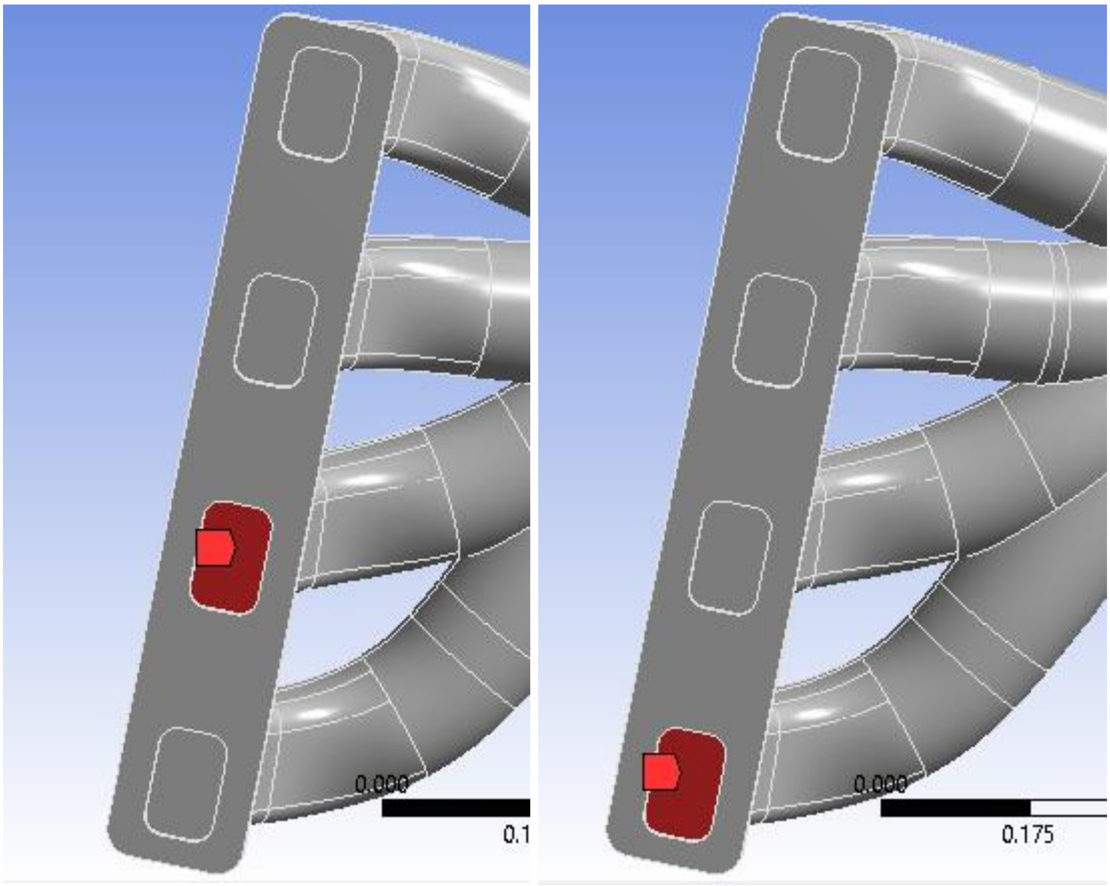


Figure 4.16.3 In-3

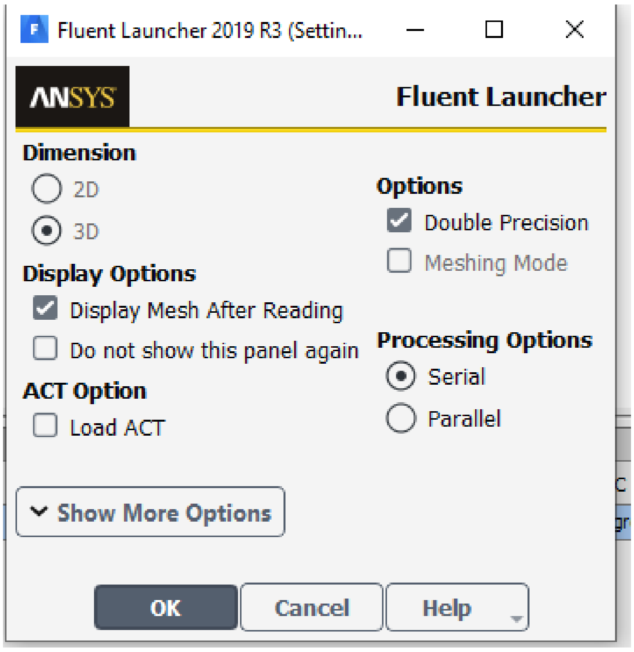
Figure 4.16.4 In-4

Figure 4.16 Input of manifold exhaust (In1, In2, In3, In4)

- By updating mesh and adding Face Sizing by element sizing of 0.005 mm the mesh has to create is:

Figure 4.17 Mesh update in Fluid Flow application

- In setup panel will used the measurement as in figure 4.18



Fluent Launcher 2019 R3 (Settin...

ANSYS

Fluent Launcher

Dimension

○ 2D

● 3D

Display Options

☑ Display Mesh After Reading

☐ Do not show this panel again

ACT Option

☐ Load ACT

Options

☑ Double Precision

☐ Meshing Mode

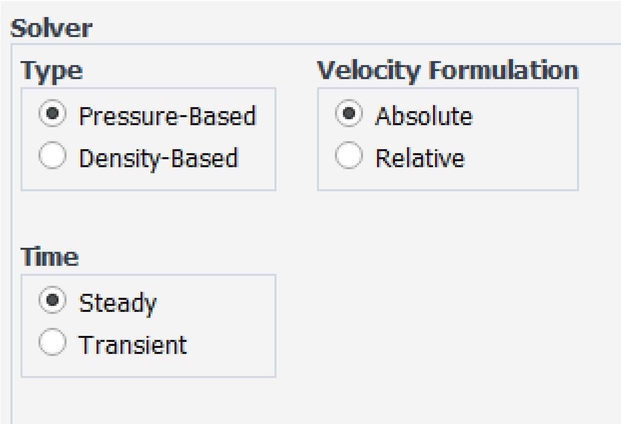
Processing Options

● Serial

○ Parallel

Figure 4.18 setup panel

- By using the needed solution characteristics to solve the manifold fluid dynamics design and applying the energy equation and calculation model as in Figure 4.19 / 4.20:



Solver

Type

● Pressure-Based
○ Density-Based

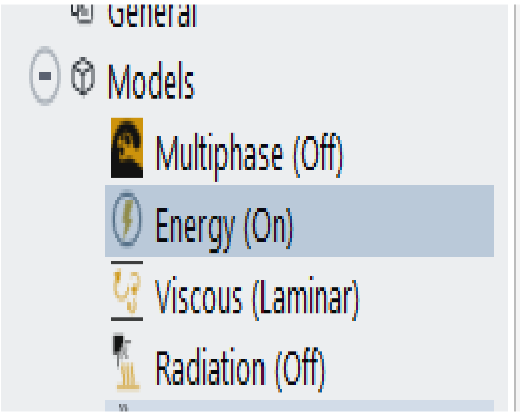
Velocity Formulation

● Absolute
○ Relative

Time

● Steady
○ Transient

Figure 4.19 General properties



General
Models
Multiphase (Off)
Energy (On)
Viscous (Laminar)
Radiation (Off)

Figure 4.20 Models tree

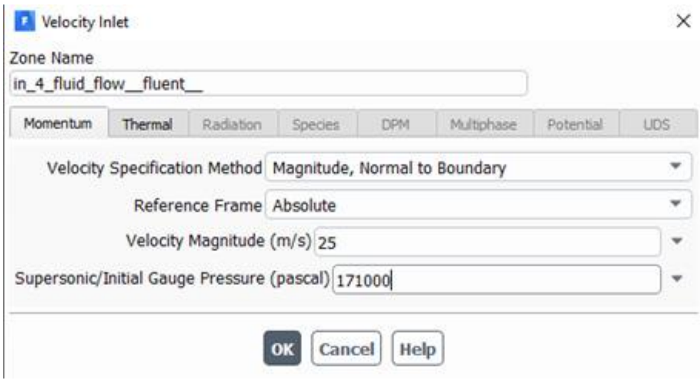
- pressure-based solver is used for incompressible and mildly compressible flows but density-based solver is designed for high-speed compressible flows in this study the fluid is mildly compressible flow.

- velocity formulation: For velocity inlets and walls can use either the absolute or the relative solution so it’s not matter in this case study.

- Energy (On): this option is to turn on the heat distribution and allow the boundary condition to generate initial heat in the calculation.

- Viscous (Laminar): Laminar in the viscous model in fluent is to the same as the direct numerical simulation (DNS) which is a simulation in computational fluid dynamics (CFD) in which the Navier–Stokes equations are numerically solved without any turbulence model.

- by defining the boundary conditions as inlet velocity with 25 (m/s) velocity magnitude and with thermal temperature equals 574.15 (k) (301 C).



Zone Name: in_4_fluid_flow__fluent__

Velocity Specification Method: Magnitude, Normal to Boundary

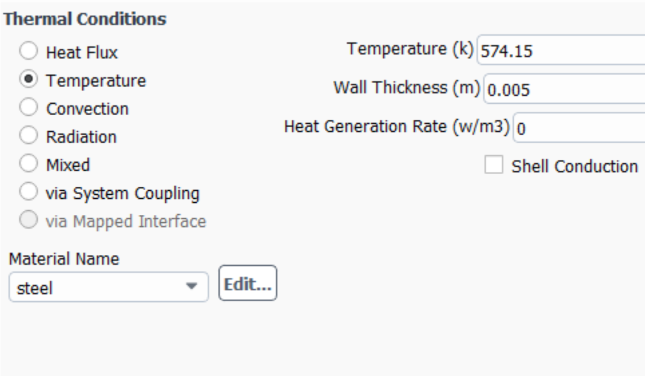
Reference Frame: Absolute

Velocity Magnitude (m/s): 25

Supersonic/Initial Gauge Pressure (pascal): 171000

Figure 4.21 inlet boundary conditions

- the walls characteristics in figure 4.22



Thermal Conditions

○ Heat Flux
● Temperature
○ Convection
○ Radiation
○ Mixed
○ via System Coupling
○ via Mapped Interface

Temperature (k): 574.15

Wall Thickness (m): 0.005

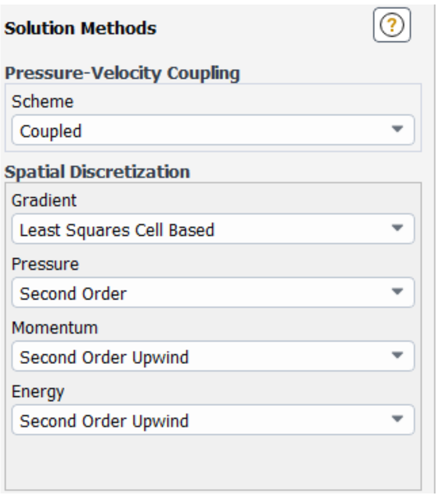
Heat Generation Rate (w/m3): 0

☐ Shell Conduction

Material Name: steel

Figure 4.22 wall boundary conditions

- The Solution Methods task page specifies various parameters associated with the solution method to be used in the calculation.



Solution Methods

Pressure-Velocity Coupling

Scheme: Coupled

Spatial Discretization

Gradient: Least Squares Cell Based

Pressure: Second Order

Momentum: Second Order Upwind

Energy: Second Order Upwind

Figure 4.23 Solution Methods

Scheme provides a drop-down list of the available pressure-velocity coupling schemes: SIMPLE, SIMPLEC, PISO, and Coupled.

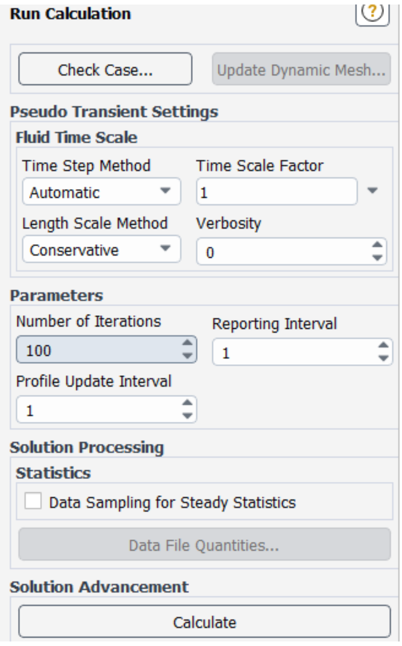
This item appears only when the pressure-based solver is used.

Gradient contains a drop-down list of the options for setting the method of computing the gradient, Green-Gauss Cell Based; Green-Gauss Node-Based, and Least Squares Cell Based.

Pressure (for the pressure-based solver only) contains a drop-down list of the discretization schemes available for the pressure equation: Standard, PRESTO! Linear, Second Order, and Body Force Weighted.

Momentum Energy, are the names of the other convection-diffusion equations being solved. In the drop-down list next to each equation, you can select the First Order Upwind, Second Order Upwind, Power Law, QUICK, or Third-Order MUSCL discretization scheme for that equation.

- Then to the calculation and the results:



Run Calculation

Pseudo Transient Settings

Fluid Time Scale

Time Step Method: Automatic

Time Scale Factor: 1

Length Scale Method: Conservative

Verbosity: 0

Parameters

Number of Iterations: 100

Reporting Interval: 1

Profile Update Interval: 1

Solution Processing

Statistics

☐ Data Sampling for Steady Statistics

Solution Advancement

Figure 4.24 Needed calculation and accuracy

- By the end of the calculation in this section, the design then will do all the simulation of fluid in the results section.

5

Chapter Five
Mechanical Part

5.1 Introduction

In this chapter we will introduce the mechanical and practical part of the project.

The flowchart describes the stage of mechanical process.

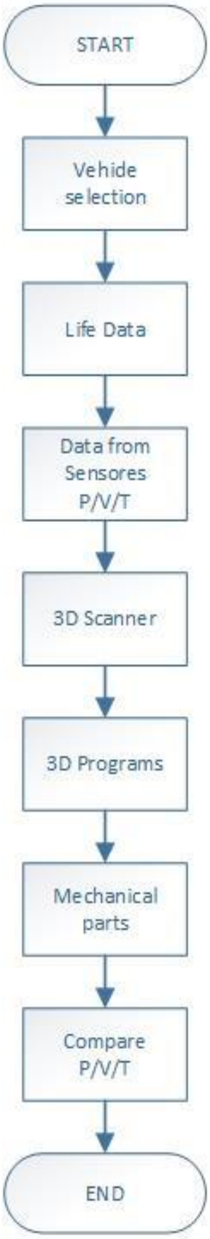


Figure 5.1 Project life cycle

5.2 Vehicle selection

General information	
Make	Renault
Model	Megane
Model year	2005
Engine type	1.6L L4 DOHC 16V
Fuel type	Gasoline
Manufactured in	France

Table 5.1General Information

5.3 Work Steps

1. In the first stage, we selected a suitable vehicle for the project and took live data for the engine
2. The exhaust manifold has been removed and a 3D scan has been made to it
3. We made the stage of turning the exhaust manifold, installing 20 cm long copper pipes to prevent the heat emitted from the manifold affecting the sensors reading, installing a temperature sensor, and then re-installing it on the engine.
4. Programming the temperature sensor with the Arduino and using the MAX6675 adapter
5. Programming the pressure sensor with PLC and calibrating the sensor
6. Start the engine and wait for the temperature to warm up, which is close to 90 degrees
7. Start taking readings after the values are proven
8. Waiting work area to cool and move the pressure sensor to a second point, and so on until all readings are taken

9. Empty the results into a table and compare them with the theoretical results and the results of the scientific paper

5.4 Life Data.

Measurements	Idle speed (before change)
Engine speed	784 RBM
Vehicle speed	0 KM/H
Ignition timing advance for #1 cylinder	0 deg
Intake air temp	29 deg c
Absolute throttle position	14.9%
Oxygen sensor B1-S1 ,voltage	0.065 V
Oxygen sensor B1-S1 ,short term fuel	-52.3%
Oxygen sensor B1-S2 ,voltage	0.47 V
Oxygen sensor B1-S2 ,short term fuel	-100 %
Long term fuel trim-Bank1	67.2 %
Short term fuel trim-Bank1	-60.2 %
MAP sensor	95 KPa
Engine coolant tem	88 deg c
Calculated load value	30.2 %

Table 5.2 Life Data

5.5 Hardware and sensors

5.5.1 Arduino

Arduino/Genuino Uno is a microcontroller board based on the ATmega328P. It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz quartz crystal, a USB connection, a power jack, an ICSP header and a reset button. It contains everything needed to support the microcontroller; simply connect

it to a computer with a USB cable or power it with an AC-to-DC adapter or battery to get started. You can tinker with your UNO without worrying too much about doing something wrong, worst case scenario you can replace the chip for a few dollars and start over again.
"Uno" means one in Italian and was chosen to mark the release of Arduino Software (IDE) 1.0. The Uno board and version 1.0 of Arduino Software (IDE) were the reference versions of Arduino, now evolved to newer releases. The Uno board is the first in a series of USB Arduino boards, and the reference model for the Arduino platform; for an extensive list of current, past or outdated boards see the Arduino index of boards.

Figure 5.2 Arduino

5.5.2 Delphi

Delphi was a part of General Motors and was spun off as an independent company on May 31, 1999. General Motors sold $3.8 billion worth of preferred shares in Delphi. While this separated Delphi from GM, they were still in a way connected at the hip as Delphi still provided parts to GM products.

This separation was not smooth as while no longer part of General Motors, the now independent company brought with it the high labor costs and pensions that it had while part of General Motors. It lost $4.8 billion in 2004 and nearly $750 million in the first half of 2005 leading to its bankruptcy. Delphi exited bankruptcy in 2009.

On 5 December 2017 Delphi Automotive renamed itself Aptiva and spun off its powertrain and aftermarket related businesses to a stand-alone company Delphi

Technologies PLC. The $4.5 billion company began trading under the former Delphi Automotive symbol DLPH on the New York Stock Exchange. It was added to the S&P MidCap 400 Index on 6 December 2017.

Figure 5.3 Delphi

5.5.3 PLC Characteristic

Programmable Logic Controller (PLC) is a digital computer used for automation of electromechanical process, such as control of machinery on factory assembly lines, PLCs are used in many industries and machine. Unlike general-purpose computers, the PLC is designed for multiple inputs and output arrangements. extended temperature ranges, immunity to electrical noise, and resistance to vibration and impact. Programs to control machine operation are typically stored in battery backed up or non- volatile memory.

A PLC is an example of a hard-real time system since output results must be produced in response to input conditions within a limited time otherwise unintended operation will result. In our controlling design it is desirable to use a PLC with 13 input and 11 outputs mention, it can be operated on 24 volts. The used PLC is Fatek base controller 24VDC with 13 inputs and 9 outputs.

Figure 5.4 PLC

5.5.4 Type K Thermocouple (Chromel/Alumel)

Type K thermocouples usually work in most applications as they are nickel based and exhibit good corrosion resistance. It is the most common sensor calibration type providing the widest operating temperature range. Due to its reliability and accuracy the Type K thermocouple is used extensively at temperatures up to 2300°F (1260°C). This type of thermocouple should be protected with a suitable metal or ceramic protection tube, especially in reducing atmospheres. In oxidizing atmospheres, such as electric furnaces, tube protection is not always necessary when other conditions are suitable; however, it is recommended for cleanliness and general mechanical protection. Type K will generally outlast Type J because the JP wire rapidly oxidizes, especially at higher temperatures.

Figure 5.5 Type K Thermocouple

5.5.5 MAX6675

This module utilizes the MAX6675 IC which is a cold-junction-compensated K-Type thermocouple to digital converter. The MAX6675 has a maximum measurement range of 0°C to +1024°C depending on the thermocouple it is paired with. Thermocouples work on the principle that dissimilar metals that are welded together at a single point will create a small voltage that will vary with the temperature. The main advantage of thermocouples over typical thermal sensing electronics such as the DS18B20 is that the sensing range can go much higher since a robust metallic probe is used to sense the temperature while the electronics hang back in a safe location. The flip side is that the reading may not be quite as accurate using a thermocouple. Thermocouples come in many different varieties from very fine wires if you want to measure a small object, to very thick metal sheathed wires with very high-temperature ranges.

Figure 5.6 MAX6675

5.5.6 OEM Pressure Transmitter

Features

1- Nominal pressure: 0 ... 10 bar.

2- Accuracy: 1 % FSO.

Benefits

1- Mechanical and plant engineering.

2- Energy industry.

3- Utility vehicles / mobile hydraulics utility vehicles / mobile hydraulic.

Figure 5.7 OEM Pressure Transmitter

5.6 Result

5.6.1 Result of the Mechanical Part

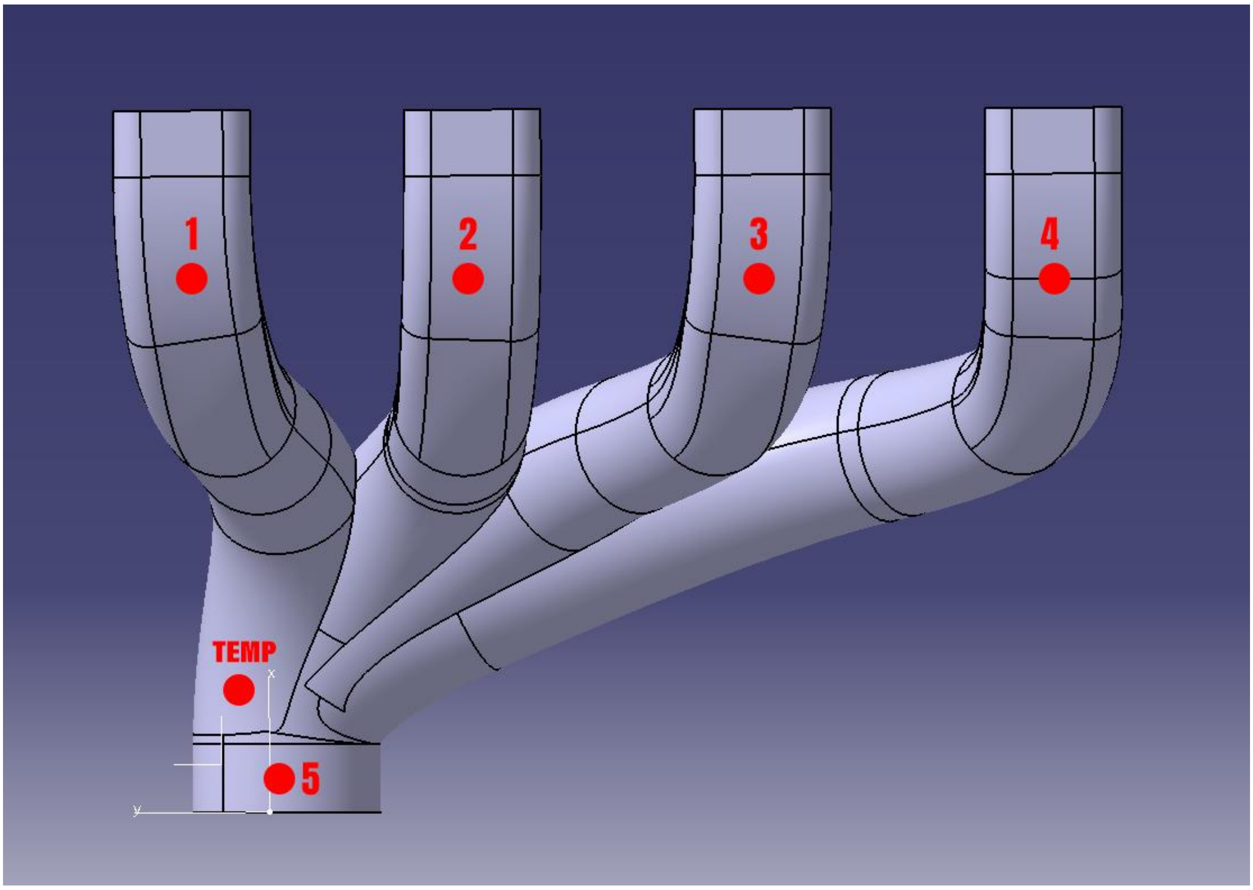


Figure 5.8 Measurement points on the exhaust manifold in the practical part

To describe the project, the picture above shows the sensor readings at different points

data	Pressure (Kpa)
1	171
2	165
3	167
4	173
5	105

Table 5.3 Data of Pressure

data	Temp (c)
1	301

Table 5.3 Data of Temperature

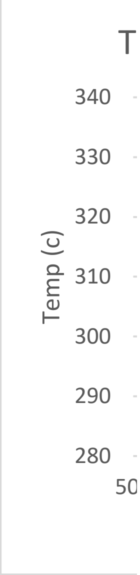


Figure 5.9 The relationship between Engine Speed & Temperature

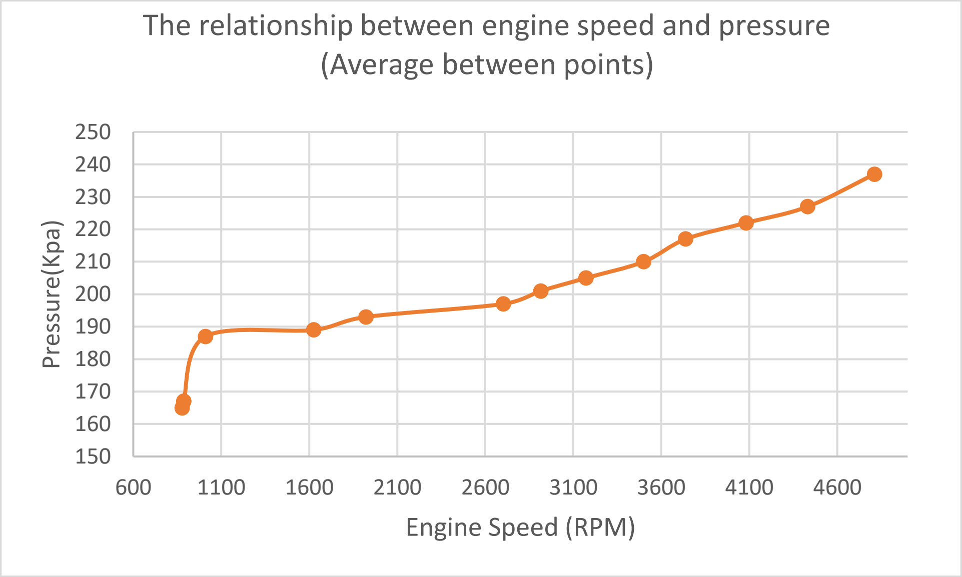


Figure 5.10 The relationship between engine speed and pressure (Average between points)

5.6.2 Results from The Scientific Paper with title (CFD Analysis of Exhaust Manifold for Different Designs)[16]

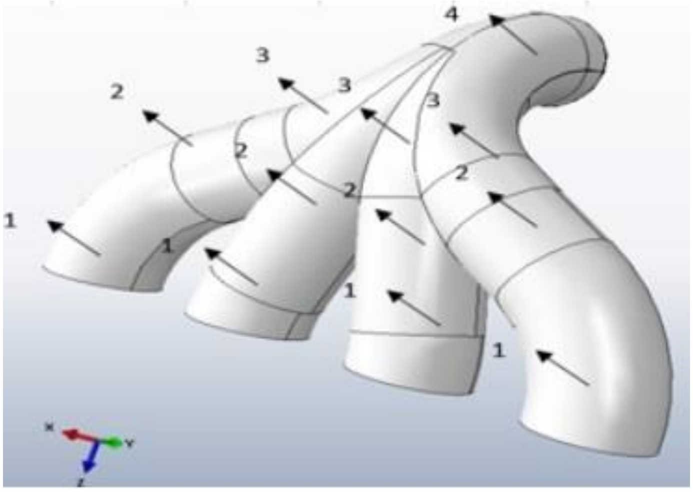


Figure 5.11 Measurement points on the exhaust manifold in the scientific paper

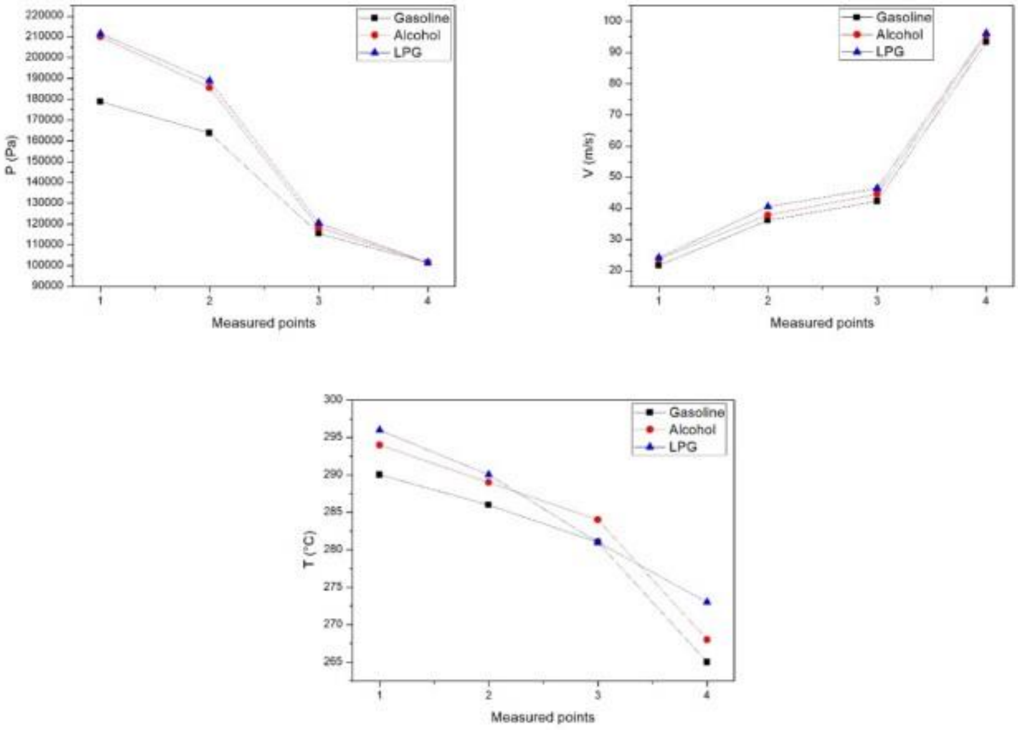


Figure 5.12 Results of The Scientific Paper(P/T/V)

5.6.3 Results of The Theoretical Part

5.6.3.1 Without Change

1- Pressure

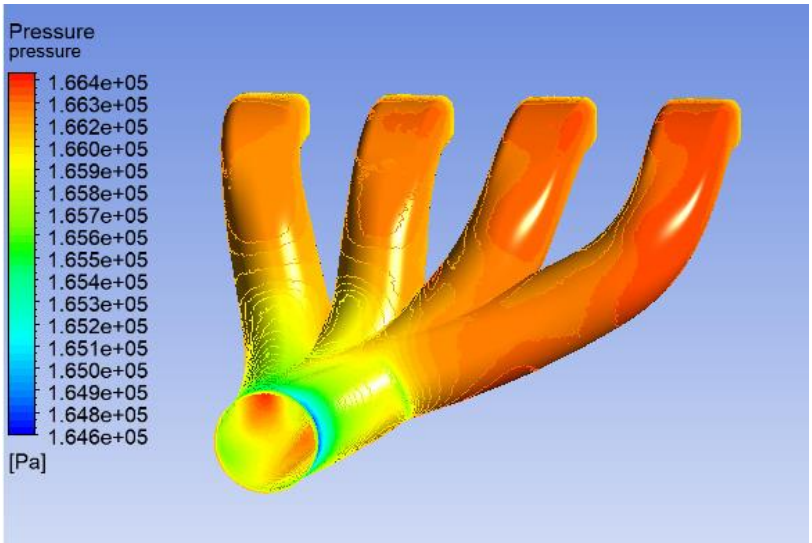


Figure 5.13 Results of The Theoretical Pressure

This is the pressure contour and it varies between 1.646 bar to 1.664 bar along the exhaust manifold body with the highest pressure in the fourth inlet and the lowest pressure near the outlet.

2- Temperature

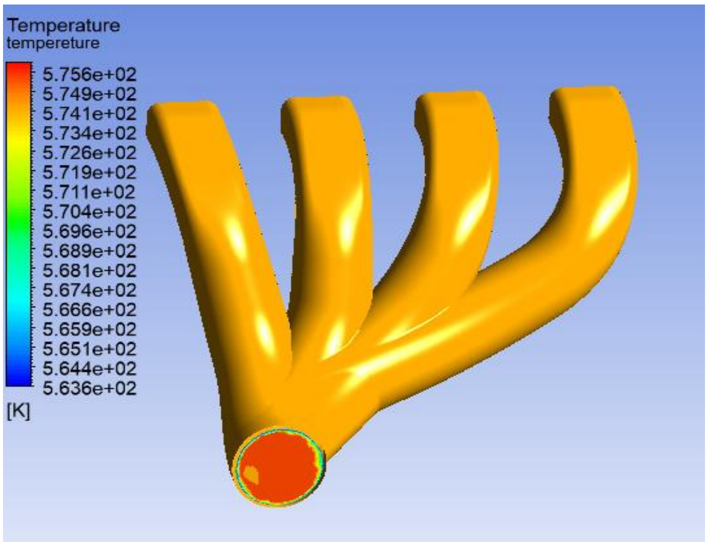


Figure 5.14 Results of The Theoretical Temperature

As the temperature distribution along the body there is not that big change happened along the body as in the figure the temperature change is 11 K.

3- Velocity

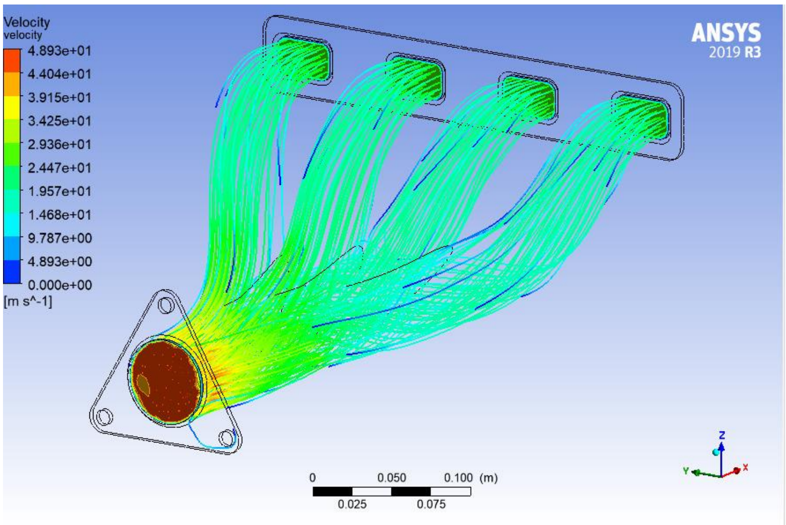


Figure 5.15 Results of The Theoretical Velocity

For velocity on the surface of body the velocity is zero in dynamic viscosity duo to no-slip condition presented as the blue stream lines and the velocity of fluid is goes from 25 m/s in the four inlets and rise to 48.93 m/s in the outlet that’s means that the velocity increase along the stream lines from start to the end.

5.6.3.2 With Change

by increase in the length of the start of the exhaust ducts with 30mm which increase velocity and decrease pressure.

1- Pressure

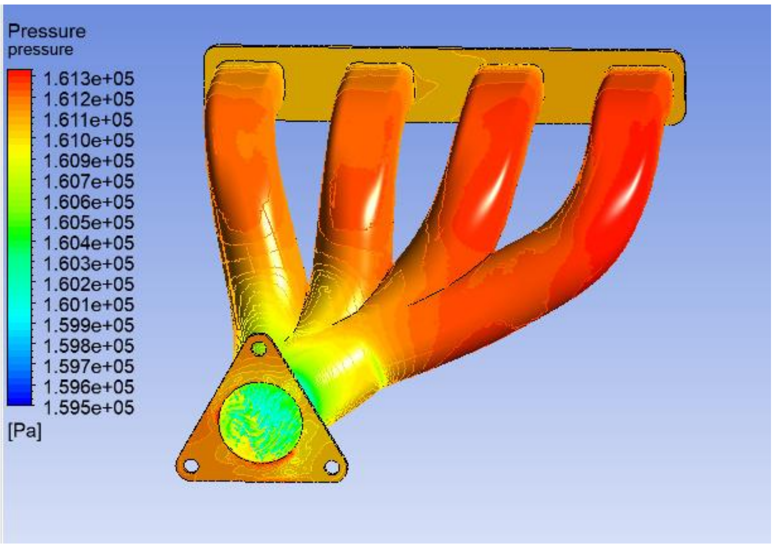


Figure 5.16 Results of The Theoretical Pressure with Change

After the change on design noticed that the maximum pressure decreases from 1.664 bar to 1.613 bar that's means lower back-pressure on the engine and effect the velocity to increase, as shown in figure 5.18 that the maximum velocity increase from 48.93 m/s to 49.24 m/s.

2- Temperature

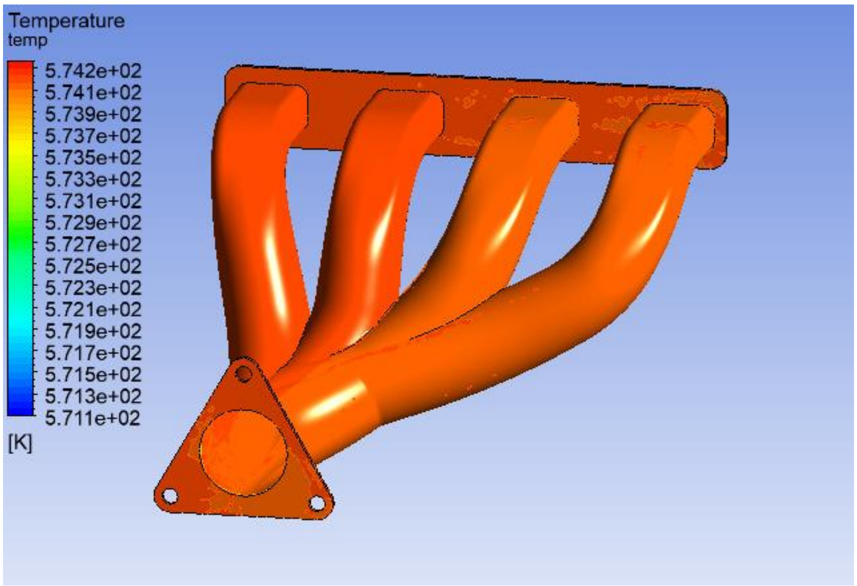


Figure 5.17 Results of The Theoretical Pressure with Change

After change the temperature distribution along the body there is changed better along the body as in the figure 5.17 the temperature change from the inlet to the outlet is 3.1 K.

3- Velocity

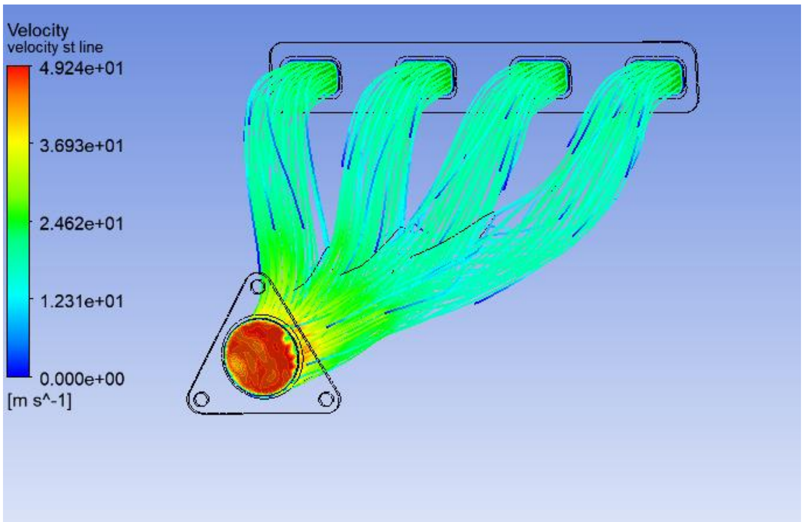


Figure 5.18 Results of The Theoretical Pressure with Change

5.7 Conclusion

The practical readings recorded by the sensors (temperature and pressure) and the velocity taken from the attached paper were compared with the theoretical readings extracted from the Ansys program, which showed great convergence and a small error rate, as the theoretical temperature was (575.6 K) and practical (574.15 K) and the theoretical pressure was (166.4 kpa) and the practical (167 kpa).

Some Objectives have been achieved theoretically using Ansys, increase the velocity of exhaust gases in the exhaust manifold with 0.31 m/s, decrease pressure with 5 kpa, and improve temperature distribution in the exhaust manifold these factors affect directly on engine work

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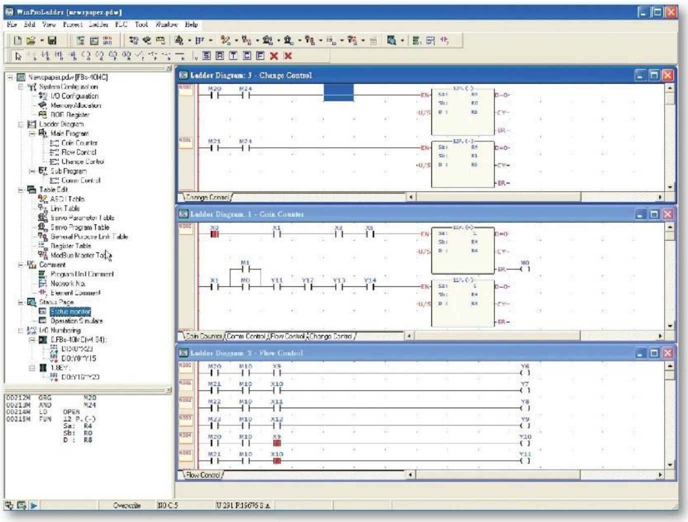
Appendix

PLC Datasheet

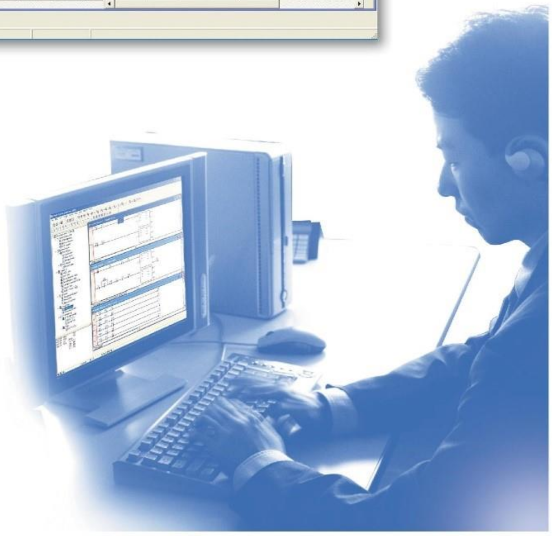
Program Development Software

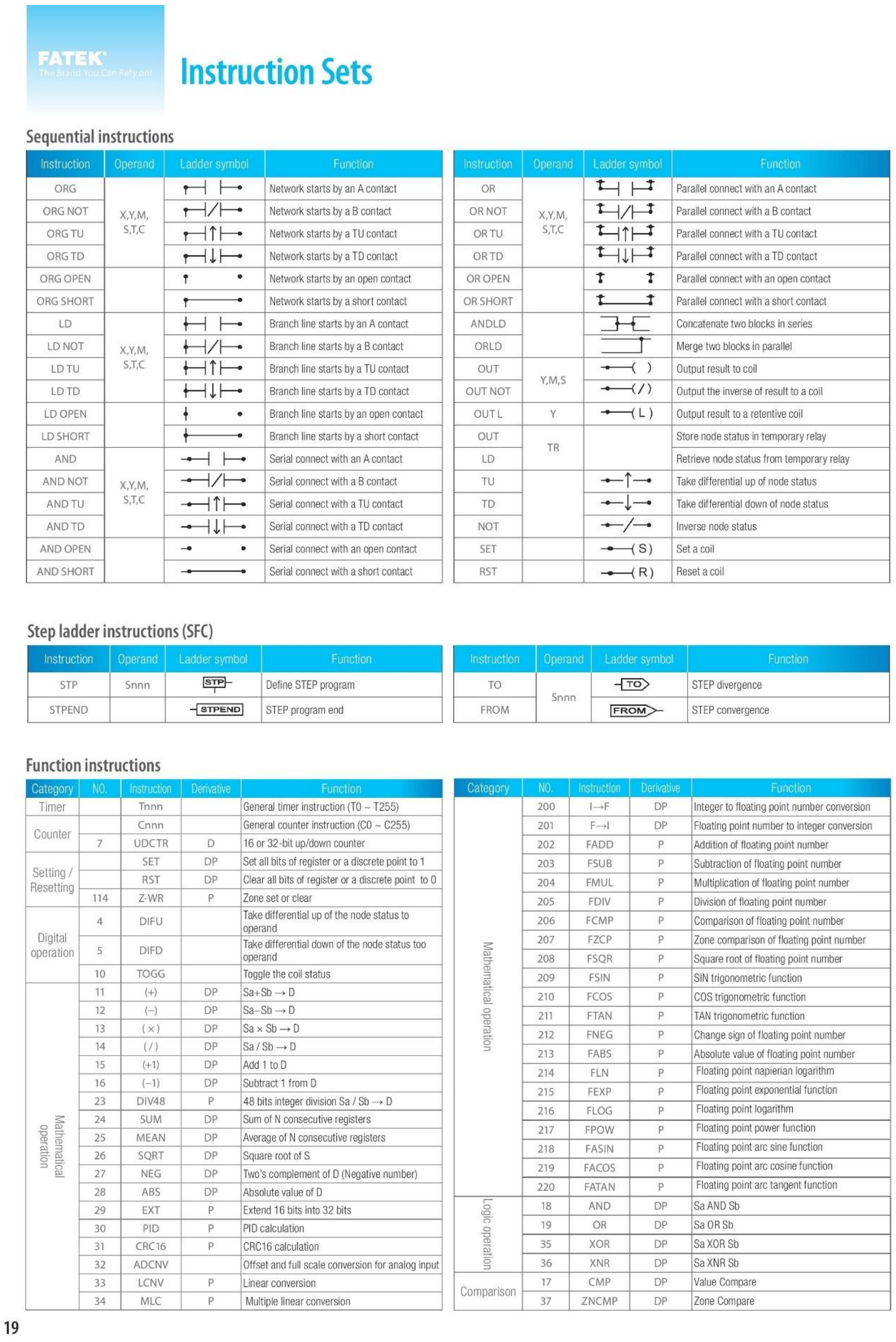
General Features

- Windows based application program following the standard conventions of a windows environment for ease of learning and operation regardless of whether the user is a beginner or frequent user.
- Application environment for project development is via a hierarchical tree. All the elements of the project can be activated by directly clicking the mouse button on the tree object providing comprehensive access and views of the working project.
- Easy entry methods which incorporate both the keyboard and mouse as entry devices. No matter whether on site or in an office environment the software can be operated with ease and efficiency.
- Provides various types of connections to the PLC via a PC. Connections include serial, USB, Ethernet / Internet and Modem. For every different connection WinProladder provides a session name to associate the setting of the communication parameters, such as port no., baud rate, IP address, phone number, etc.



- On-Line, Run-Time program editing
- Program testing
- Program comments
- Project oriented program
- Ladder program editing screen
- Status monitor and control
- Mnemonic ladder instruction display window
- Ladder diagram with comments
- Element comment editing
- Off-Line Simulation





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Instruction Sets

Sequential instructions

Instruction	Operand	Ladder symbol	Function
ORG	X,Y,M, S,T,C		Network starts by an A contact
ORG NOT			Network starts by a B contact
ORG TU			Network starts by a TU contact
ORG TD			Network starts by a TD contact
ORG OPEN			Network starts by an open contact
ORG SHORT			Network starts by a short contact
LD	X,Y,M, S,T,C		Branch line starts by an A contact
LD NOT			Branch line starts by a B contact
LD TU			Branch line starts by a TU contact
LD TD			Branch line starts by a TD contact
LD OPEN			Branch line starts by an open contact
LD SHORT			Branch line starts by a short contact
AND	X,Y,M, S,T,C		Serial connect with an A contact
AND NOT			Serial connect with a B contact
AND TU			Serial connect with a TU contact
AND TD			Serial connect with a TD contact
AND OPEN			Serial connect with an open contact
AND SHORT			Serial connect with a short contact

Instruction	Operand	Ladder symbol	Function
OR	X,Y,M, S,T,C		Parallel connect with an A contact
OR NOT			Parallel connect with a B contact
OR TU			Parallel connect with a TU contact
OR TD			Parallel connect with a TD contact
OR OPEN			Parallel connect with an open contact
OR SHORT			Parallel connect with a short contact
ANDLD			Concatenate two blocks in series
ORLD			Merge two blocks in parallel
OUT	Y,M,S	( )	Output result to coil
OUT NOT		(/)	Output the inverse of result to a coil
OUT L	Y	(L)	Output result to a retentive coil
OUT	TR		Store node status in temporary relay
LD			Retrieve node status from temporary relay
TU		↑	Take differential up of node status
TD		↓	Take differential down of node status
NOT		/	Inverse node status
SET		(S)	Set a coil
RST		(R)	Reset a coil

Step ladder instructions (SFC)

Instruction	Operand	Ladder symbol	Function
STP	Snnn	STP	Define STEP program
STPEND		STPEND	STEP program end

Instruction	Operand	Ladder symbol	Function
TO	Snnn	TO	STEP divergence
FROM		FROM	STEP convergence

Function instructions

Category	NO.	Instruction	Derivative	Function
Timer		Tnnn		General timer instruction (T0 ~ T255)
Counter		Cnnn		General counter instruction (C0 ~ C255)
	7	UDCTR	D	16 or 32-bit up/down counter
Setting / Resetting		SET	DP	Set all bits of register or a discrete point to 1
		RST	DP	Clear all bits of register or a discrete point to 0
	114	Z-WR	P	Zone set or clear
Digital operation	4	DIFU		Take differential up of the node status to operand
	5	DIFD		Take differential down of the node status too operand
	10	TOGG		Toggle the coil status
Mathematical operation	11	(+)	DP	Sa+Sb → D
	12	(–)	DP	Sa–Sb → D
	13	(×)	DP	Sa × Sb → D
	14	(/)	DP	Sa / Sb → D
	15	(+1)	DP	Add 1 to D
	16	(–1)	DP	Subtract 1 from D
	23	DIV48	P	48 bits integer division Sa / Sb → D
	24	SUM	DP	Sum of N consecutive registers
	25	MEAN	DP	Average of N consecutive registers
	26	SQRT	DP	Square root of S
	27	NEG	DP	Two's complement of D (Negative number)
	28	ABS	DP	Absolute value of D
	29	EXT	P	Extend 16 bits into 32 bits
	30	PID	P	PID calculation
	31	CRC16	P	CRC16 calculation
	32	ADCNV		Offset and full scale conversion for analog input
	33	LCNV	P	Linear conversion
	34	MLC	P	Multiple linear conversion

Category	NO.	Instruction	Derivative	Function
Mathematical operation	200	I→F	DP	Integer to floating point number conversion
	201	F→I	DP	Floating point number to integer conversion
	202	FADD	P	Addition of floating point number
	203	FSUB	P	Subtraction of floating point number
	204	FMUL	P	Multiplication of floating point number
	205	FDIV	P	Division of floating point number
	206	FCMP	P	Comparison of floating point number
	207	FZCP	P	Zone comparison of floating point number
	208	FSQR	P	Square root of floating point number
	209	FSIN	P	SIN trigonometric function
	210	FCOS	P	COS trigonometric function
	211	FTAN	P	TAN trigonometric function
	212	FNEG	P	Change sign of floating point number
	213	FABS	P	Absolute value of floating point number
	214	FLN	P	Floating point napierian logarithm
	215	FEXP	P	Floating point exponential function
	216	FLOG	P	Floating point logarithm
	217	FPOW	P	Floating point power function
	218	FASIN	P	Floating point arc sine function
	219	FACOS	P	Floating point arc cosine function
	220	FATAN	P	Floating point arc tangent function
Logic operation	18	AND	DP	Sa AND Sb
	19	OR	DP	Sa OR Sb
	35	XOR	DP	Sa XOR Sb
	36	XNR	DP	Sa XNR Sb
Comparison	17	CMP	DP	Value Compare
	37	ZNCMP	DP	Zone Compare

Instruction Sets

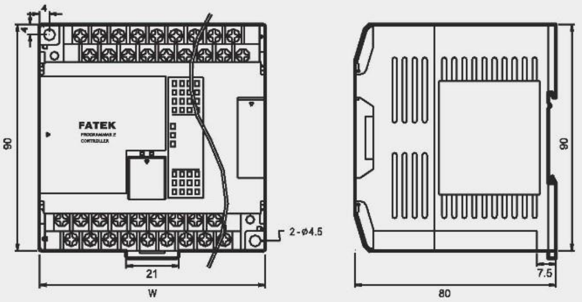
(Continue)

Category	NO.	Instruction	Derivative	Function
Move operation	8	MOV	DP	Move S to D
	9	MOV/	DP	Inverse S and move to D
	40	BITRD	DP	Move the Bit-N of S to FO
	41	BITWR	DP	Write INB input to the Bit-N of D
	42	BITMV	DP	Move the Bit-Ns of S to the Bit -Nd of D
	43	NBMV	DP	Move the Nibble-Ns of S to the Nibble-Nd of D
	44	BYMV	DP	Move the Byte-Ns of S to the Byte-Nd of D
	45	XCHG	DP	Exchange Da and Db
	46	SWAP	P	Swap the High-Byte of D with the Low-Byte of D
	47	UNIT	P	Take Nb0 of N words to form a Word
	48	DIST	P	Distribute N Nb of S to Nb0 of N Words
	49	BUNIT	P	Low byte of words re-unit
	50	BDIST	P	Words split into multi-byte
	160	RW-FR	DP	File register access
	161	WR-MP		Write memory pack
	162	RD-MP	P	Read memory pack
Shift / Rotation	6	BSHF	DP	Shift D right 1 bit or left 1 bit
	51	SHFL	DP	Shift D left N bits
	52	SHFR	DP	Shift D right N bits
	53	ROTL	DP	Rotate D left N bits
	54	ROTR	DP	Rotate D right N bits
Code conversion	20	→BCD	DP	Convert S into BCD
	21	→BIN	DP	Convert S into Binary
	55	B→G	DP	Binary to Gray code conversion
	56	G→B	DP	Gray code to Binary conversion
	57	DECOD	P	Decode the Ns ~ Nl of S
	58	ENCOD	P	Encode the Ns ~ Nl of S
	59	→7SG	P	Convert N+1' Nb of S into 7-segment code
	60	→ASC	P	Convert character/number into ASCII code
	61	→SEC	P	Convert hour, minute, second by seconds
	62	→HMS	P	Convert second by hour, minute and second
	63	→HEX	P	Convert ASCII code into hexadecimal
	64	→ASCII	P	Convert hexadecimal into ASCII code
Flow control	0	MC		Master control loop start
	1	MCE		Master control loop end
	2	SKP		The start of the skip loop
	3	SKPE		The end of the skip loop
		END		Terminate the execution of program (for debugging)
	22	BREAK	P	Exit from FOR-NEXT loop
	65	LBL		Define the string as label
	66	JMP	P	Jump instruction
	67	CALL	P	Call instruction
	68	RTS		Subroutine return instruction
	69	RTI		Interrupt return instruction
	70	FOR		The start of the FOR loop
	71	NEXT		Return point of FOR loop
I/O instruction	74	IMDIO	P	Refresh I/O immediately
	76	TKEY	D	10 keys input convenient instruction
	77	HKEY	D	16 keys input convenient instruction
	78	DSW	D	Thumbwheel switch input convenient instruction
	79	7SGDL	D	7-segment multiplexing display convenient Instruction
	80	MUXI		Multiplexing input convenient instruction
	81	PLSO	D	Pulse output(PSO) instruction
	82	PWM		Pulse Width Modulation (PWM) output instruction
	83	SPD		Pulse speed detection instruction
	84	TDSP		7/16-segment LED display control
	86	TPCTL		PID temperature control
	139	HSPWM		High speed PWM pulse output

Category	NO.	Instruction	Derivative	Function
Accumulative Timer	87	T.01S		0.01S time base accumulative timer
	88	T.1S		0.1S time base accumulative timer
	89	T1S		1S time base accumulative timer
Monitor and control	90	WDT	P	Set watchdog timer
	91	RSWDT	P	Reset watchdog timer
HSC/HST	92	HSCTR	P	Read CV of hardware high speed counter/timer
	93	HSCTW	P	Write CV or PV of hardware high speed counter/timer
Text	94	ASCWR		Output ASCII message
Ascend/ Descend	95	RAMP		Ascending/Descending convenient instruction
	98	RAMP2		Tracking type RAMP function for D/A output
Communication	150	M-BUS		Modbus protocol communication
	151	CLINK		Fatek CPU link/Generic protocol communication
Table operation	100	R→T	DP	Move register Rs to the table Td
	101	T→R	DP	Move the Rp of table Ts to register Rd
	102	T→T	DP	Move the Rp of table Ts to the Rp of table Td
	103	BT_M	DP	Move table Ts to table Td
	104	T_SWP	DP	Swap Ta and Tb
	105	R-T_S	DP	Search Rs from table Ts
	106	T-T_C	DP	Compare table Ta and table Tb
	107	T_FIL	DP	Fill Rs into Td table
	108	T_SHF	DP	Shift table left or right
	109	T_ROT	DP	Rotate table left or right
	110	QUEUE	DP	First in first out (Queue) instruction
	111	STACK	DP	First in last out (Stack) instruction
	112	BKCMP	DP	Compare Rs with zone defined by two tables
	113	SORT	DP	Sort the table
Matrix operation	120	MAND	P	AND two matrixes
	121	MOR	P	OR two matrixes
	122	MXOR	P	Exclusive OR (XOR) two matrixes
	123	MXNR	P	Exclusive NOR (XNR) two matrixes
	124	MINV	P	Inverse matrix
	125	MCMP	P	Compare two matrixes and find out the differences between two matrixes
	126	MBRD	P	Read the bit of a matrix pointed by pointer
	127	MBWR	P	Write the bit of a matrix pointed by pointer
	128	MBSHF	P	Shift matrix left 1 bit or right 1 bit
	129	MBROT	P	Rotate matrix left 1 bit or right 1 bit
	130	MBCNT	P	Count the number of bit whose value is 1 or 0 in the matrix
NC position control	140	HSPSO		High-speed pulse output
	141	MPARA		Set NC position parameters
	142	PSOFF	P	Force to stop pulse output
	143	PSCNV	P	Convert pulse count into mechanical value for display
	147	MHSPO		Multi-Axis high speed pulse output
	148	MPG		Manual pulse generator for positioning
Interrupt control	145	EN	P	Enable external input or peripheral interrupt
	146	DIS	P	Disable external input or peripheral interrupt
In Line Comparison Instructions	170	=	D	Equal to compare
	171	>	D	Greater than compare
	172	<	D	Less than compare
	173	<>	D	Not equal to compare
	174	>=	D	Greater than or equal to compare
	175	=<	D	Less than or equal to compare
Other	190	STAT		Read system status

Dimensions

Figure 1



W	Model
90mm	FBs-20M△,FBs-24M△,FBs-24XY FBs-16TC,FBs-16RTD
130mm	FBs-32M△,FBs-40M△,FBs-40XY
175mm	FBs-44MN△,FBs-60M△,FBs-60XY, FBs-30GM

Figure 2

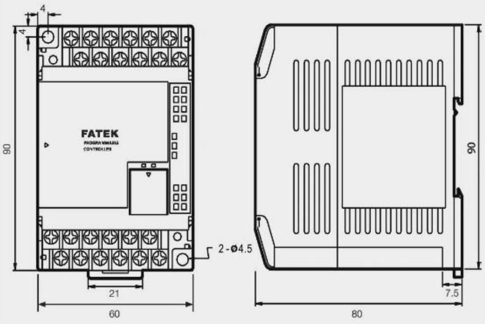


Figure 3

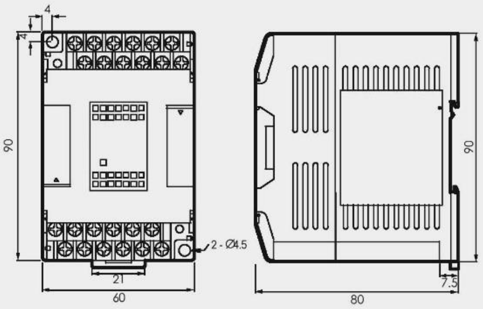


Figure 4

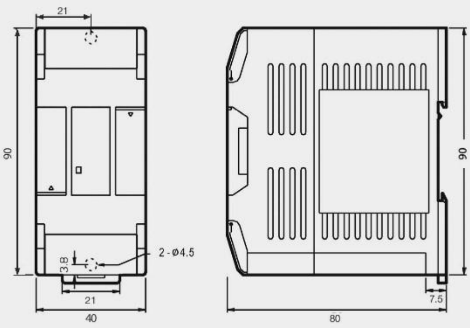
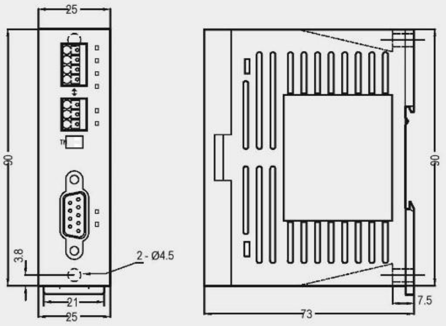
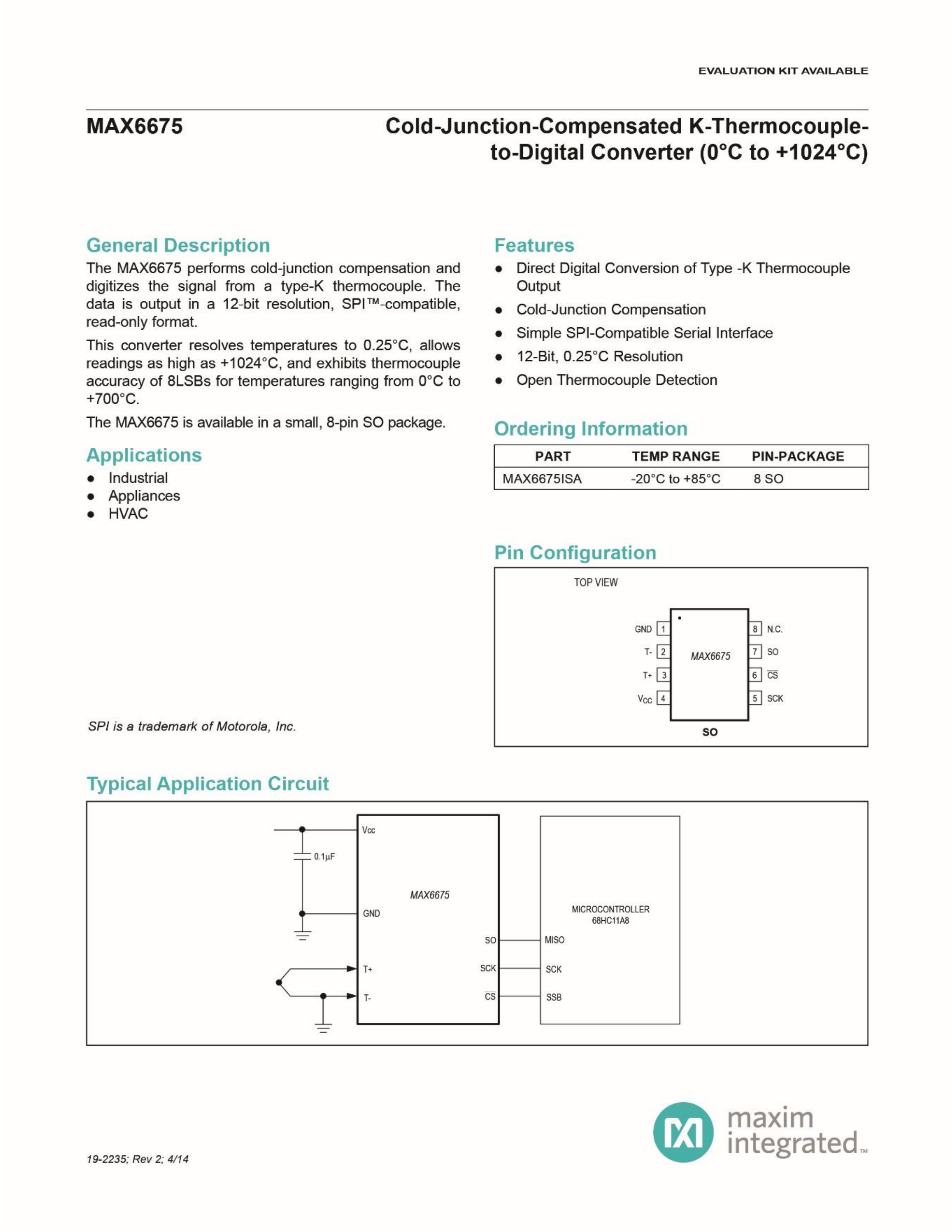


Figure 5



MAX6675 DataSheet



EVALUATION KIT AVAILABLE

MAX6675

Cold-Junction-Compensated K-Thermocouple-to-Digital Converter (0°C to +1024°C)

General Description

The MAX6675 performs cold-junction compensation and digitizes the signal from a type-K thermocouple. The data is output in a 12-bit resolution, SPI™-compatible, read-only format.

This converter resolves temperatures to 0.25°C, allows readings as high as +1024°C, and exhibits thermocouple accuracy of 8LSBs for temperatures ranging from 0°C to +700°C.

The MAX6675 is available in a small, 8-pin SO package.

Applications

- Industrial
- Appliances
- HVAC

SPI is a trademark of Motorola, Inc.

Features

- Direct Digital Conversion of Type -K Thermocouple Output
- Cold-Junction Compensation
- Simple SPI-Compatible Serial Interface
- 12-Bit, 0.25°C Resolution
- Open Thermocouple Detection

Ordering Information

PART	TEMP RANGE	PIN-PACKAGE
MAX6675ISA	-20°C to +85°C	8 SO

Pin Configuration

Typical Application Circuit

19-2235; Rev 2; 4/14

maxim integrated™

Absolute Maximum Ratings

Supply Voltage (V_{CC} to GND) .... -0.3V to +6V
SO, SCK, $\overline{CS}$, T-, T+ to GND ....-0.3V to V_{CC} + 0.3V
SO Current 50mA
ESD Protection (Human Body Model) .... ±2000V
Continuous Power Dissipation (T_A = +70°C)
8-Pin SO (derate 5.88mW/°C above +70°C) 471mW
Operating Temperature Range .... -20°C to +85°C
Storage Temperature Range .... -65°C to +150°C
Junction Temperature .... +150°C
SO Package
Vapor Phase (60s) ....+215°C
Infrared (15s) ....+220°C
Lead Temperature (soldering, 10s) .... +300°C

Stresses beyond those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated in the operational sections of the specifications is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

Electrical Characteristics

(V_{CC} = +3.0V to +5.5V, T_A = -20°C to +85°C, unless otherwise noted. Typical values specified at +25°C.) (Note 1)

PARAMETER	SYMBOL	CONDITIONS		MIN	TYP	MAX	UNITS
Temperature Error		$T_{THERMOCOUPLE}$ = +700°C, T_A = +25°C (Note 2)	V_{CC} = +3.3V	-5		+5	LSB
			V_{CC} = +5V	-6		+6	
		$T_{THERMOCOUPLE}$ = 0°C to +700°C, T_A = +25°C (Note 2)	V_{CC} = +3.3V	-8		+8	
			V_{CC} = +5V	-9		+9	
		$T_{THERMOCOUPLE}$ = +700°C to +1000°C, T_A = +25°C (Note 2)	V_{CC} = +3.3V	-17		+17	
			V_{CC} = +5V	-19		+19	
Thermocouple Conversion Constant					10.25		µV/LSB
Cold-Junction Compensation Error		T_A = -20°C to +85°C (Note 2)	V_{CC} = +3.3V	-3.0		+3.0	°C
			V_{CC} = +5V	-3.0		+3.0	
Resolution					0.25		°C
Thermocouple Input Impedance					60		kΩ
Supply Voltage	V_{CC}			3.0		5.5	V
Supply Current	I_{CC}				0.7	1.5	mA
Power-On Reset Threshold		V_{CC} rising		1	2	2.5	V
Power-On Reset Hysteresis					50		mV
Conversion Time		(Note 2)			0.17	0.22	s
SERIAL INTERFACE							
Input Low Voltage	V_{IL}					0.3 x V_{CC}	V
Input High Voltage	V_{IH}			0.7 x V_{CC}			V
Input Leakage Current	I_{LEAK}	V_{IN} = GND or V_{CC}				±5	µA
Input Capacitance	C_{IN}				5		pF

Electrical Characteristics (continued)

(V_{CC} = +3.0V to +5.5V, T_A = -20°C to +85°C, unless otherwise noted. Typical values specified at +25°C.) (Note 1)

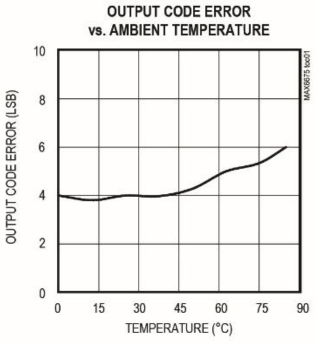
PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
Output High Voltage	V_{OH}	I_{SOURCE} = 1.6mA	V_{CC} - 0.4			V
Output Low Voltage	V_{OL}	I_{SINK} = 1.6mA			0.4	V
TIMING						
Serial Clock Frequency	f_{SCL}				4.3	MHz
SCK Pulse High Width	t_{CH}		100			ns
SCK Pulse Low Width	t_{CL}		100			ns
CSB Fall to SCK Rise	t_{CSS}	C_L = 10pF	100			ns
CSB Fall to Output Enable	t_{DV}	C_L = 10pF			100	ns
CSB Rise to Output Disable	t_{TR}	C_L = 10pF			100	ns
SCK Fall to Output Data Valid	t_{DO}	C_L = 10pF			100	ns

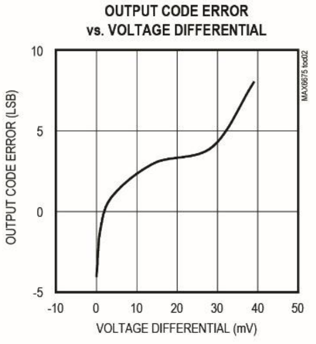
Note 1: All specifications are 100% tested at T_A = +25°C. Specification limits over temperature (T_A = T_{MIN} to T_{MAX}) are guaranteed by design and characterization, not production tested.

Note 2: Guaranteed by design. Not production tested.

Typical Operating Characteristics

(V_{CC} = +3.3V, T_A = +25°C, unless otherwise noted.)





Pin Description

PIN	NAME	FUNCTION
1	GND	Ground
2	T-	Alumel Lead of Type-K Thermocouple. Should be connected to ground externally.
3	T+	Chromel Lead of Type-K Thermocouple
4	V_{CC}	Positive Supply. Bypass with a 0.1µF capacitor to GND.
5	SCK	Serial Clock Input
6	$\overline{CS}$	Chip Select. Set $\overline{CS}$ low to enable the serial interface.
7	SO	Serial Data Output
8	N.C.	No Connection

Detailed Description

The MAX6675 is a sophisticated thermocouple-to-digital converter with a built-in 12-bit analog-to-digital converter (ADC). The MAX6675 also contains cold-junction compensation sensing and correction, a digital controller, an SPI-compatible interface, and associated control logic.

The MAX6675 is designed to work in conjunction with an external microcontroller (µC) or other intelligence in thermostatic, process-control, or monitoring applications.

Temperature Conversion

The MAX6675 includes signal-conditioning hardware to convert the thermocouple's signal into a voltage compatible with the input channels of the ADC. The T+and T- inputs connect to internal circuitry that reduces the introduction of noise errors from the thermocouple wires.

Before converting the thermoelectric voltages into equivalent temperature values, it is necessary to compensate for the difference between the thermocouple cold-junction side (MAX6675 ambient temperature) and a 0°C virtual reference. For a type-K thermocouple, the voltage changes by 41µV/°C, which approximates the thermocouple characteristic with the following linear equation:

$$V_{OUT} = (41\mu V / {}^{\circ}C)\ 5\ (T_R - T_{AMB})$$

Where:

V_{OUT} is the thermocouple output voltage (µV).

T_R is the temperature of the remote thermocouple junction (°C).

T_{AMB} is the ambient temperature (°C).

Cold-Junction Compensation

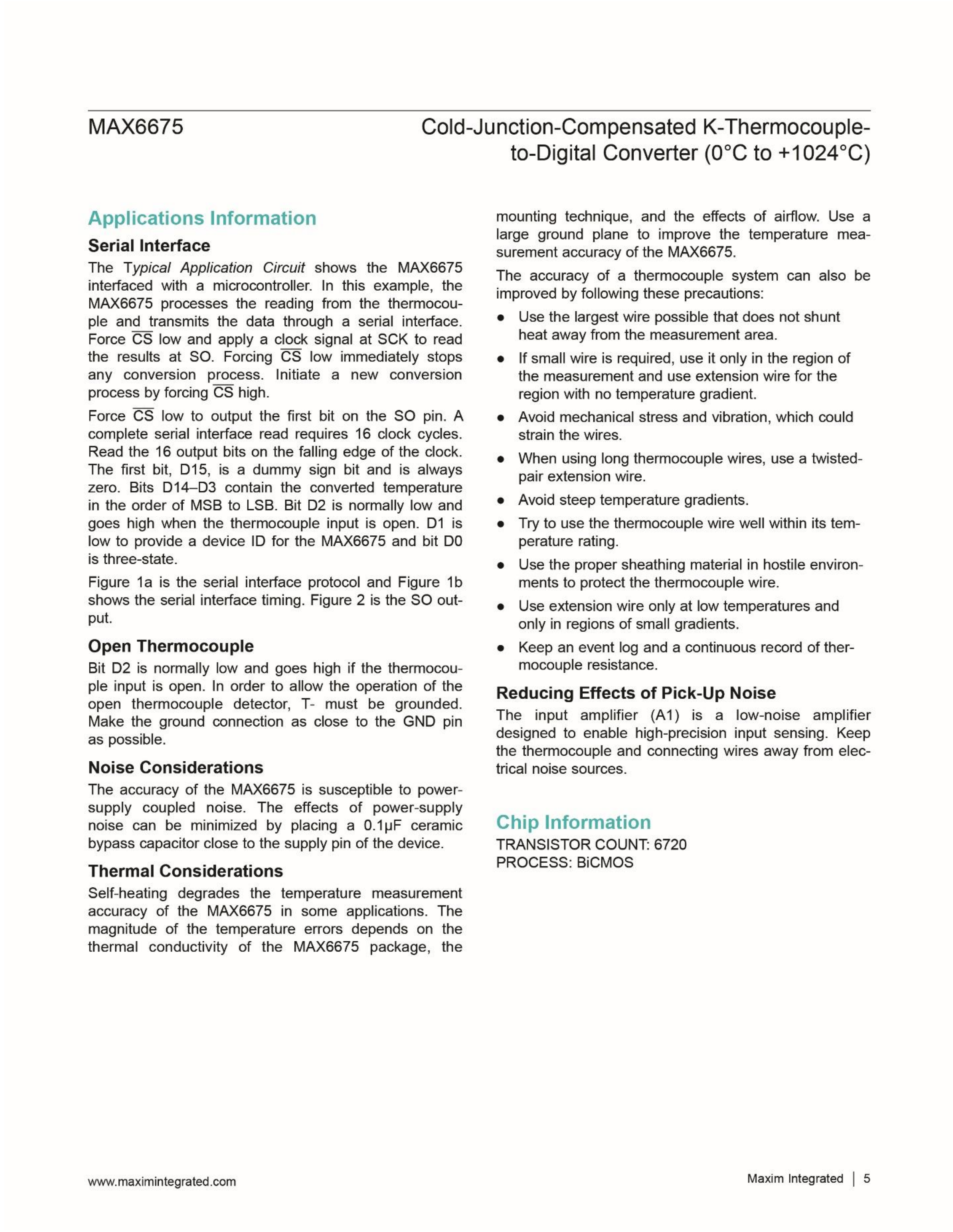
The function of the thermocouple is to sense a difference in temperature between two ends of the thermocouple wires. The thermocouple's hot junction can be read from 0°C to +1023.75°C. The cold end (ambient temperature of the board on which the MAX6675 is mounted) can only range from -20°C to +85°C. While the temperature at the cold end fluctuates, the MAX6675 continues to accurately sense the temperature difference at the opposite end.

The MAX6675 senses and corrects for the changes in the ambient temperature with cold-junction compensation. The device converts the ambient temperature reading into a voltage using a temperature-sensing diode. To make the actual thermocouple temperature measurement, the MAX6675 measures the voltage from the thermocouple's output and from the sensing diode. The device's internal circuitry passes the diode's voltage (sensing ambient temperature) and thermocouple voltage (sensing remote temperature minus ambient temperature) to the conversion function stored in the ADC to calculate the thermocouple's hot-junction temperature.

Optimal performance from the MAX6675 is achieved when the thermocouple cold junction and the MAX6675 are at the same temperature. Avoid placing heat-generating devices or components near the MAX6675 because this may produce cold-junction-related errors.

Digitization

The ADC adds the cold-junction diode measurement with the amplified thermocouple voltage and reads out the 12-bit result onto the SO pin. A sequence of all zeros means the thermocouple reading is 0°C. A sequence of all ones means the thermocouple reading is +1023.75°C.



Applications Information

Serial Interface

The T*ypical Application Circuit* shows the MAX6675 interfaced with a microcontroller. In this example, the MAX6675 processes the reading from the thermocouple and transmits the data through a serial interface. Force $\overline{\text{CS}}$ low and apply a clock signal at SCK to read the results at SO. Forcing $\overline{\text{CS}}$ low immediately stops any conversion process. Initiate a new conversion process by forcing $\overline{\text{CS}}$ high.

Force $\overline{\text{CS}}$ low to output the first bit on the SO pin. A complete serial interface read requires 16 clock cycles. Read the 16 output bits on the falling edge of the clock. The first bit, D15, is a dummy sign bit and is always zero. Bits D14–D3 contain the converted temperature in the order of MSB to LSB. Bit D2 is normally low and goes high when the thermocouple input is open. D1 is low to provide a device ID for the MAX6675 and bit D0 is three-state.

Figure 1a is the serial interface protocol and Figure 1b shows the serial interface timing. Figure 2 is the SO output.

Open Thermocouple

Bit D2 is normally low and goes high if the thermocouple input is open. In order to allow the operation of the open thermocouple detector, T- must be grounded. Make the ground connection as close to the GND pin as possible.

Noise Considerations

The accuracy of the MAX6675 is susceptible to power-supply coupled noise. The effects of power-supply noise can be minimized by placing a 0.1µF ceramic bypass capacitor close to the supply pin of the device.

Thermal Considerations

Self-heating degrades the temperature measurement accuracy of the MAX6675 in some applications. The magnitude of the temperature errors depends on the thermal conductivity of the MAX6675 package, the mounting technique, and the effects of airflow. Use a large ground plane to improve the temperature measurement accuracy of the MAX6675.

The accuracy of a thermocouple system can also be improved by following these precautions:

- Use the largest wire possible that does not shunt heat away from the measurement area.
- If small wire is required, use it only in the region of the measurement and use extension wire for the region with no temperature gradient.
- Avoid mechanical stress and vibration, which could strain the wires.
- When using long thermocouple wires, use a twisted-pair extension wire.
- Avoid steep temperature gradients.
- Try to use the thermocouple wire well within its temperature rating.
- Use the proper sheathing material in hostile environments to protect the thermocouple wire.
- Use extension wire only at low temperatures and only in regions of small gradients.
- Keep an event log and a continuous record of thermocouple resistance.

Reducing Effects of Pick-Up Noise

The input amplifier (A1) is a low-noise amplifier designed to enable high-precision input sensing. Keep the thermocouple and connecting wires away from electrical noise sources.

Chip Information

TRANSISTOR COUNT: 6720
PROCESS: BiCMOS

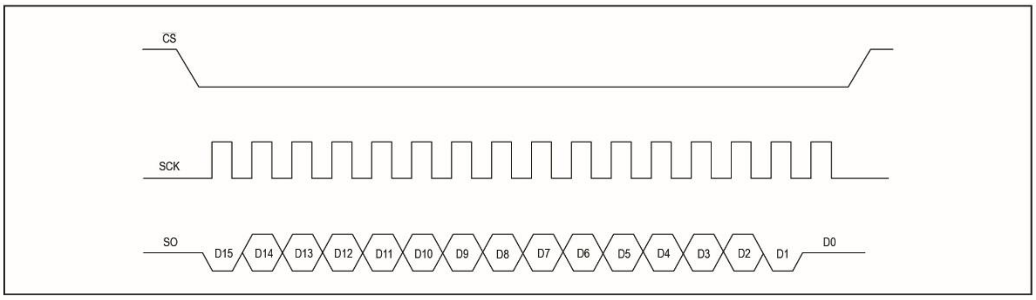


Figure 1a. Serial Interface Protocol

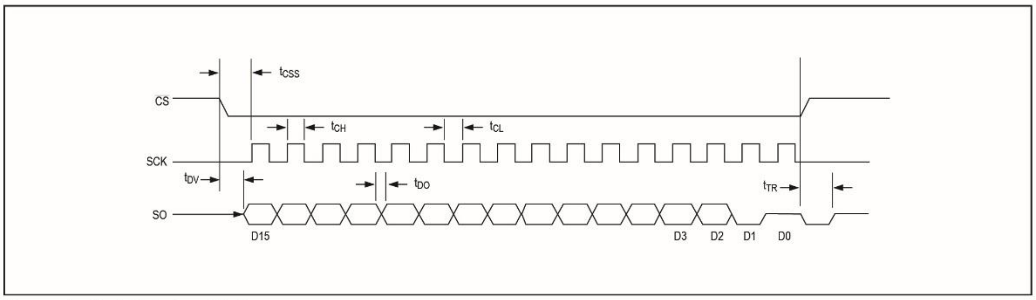
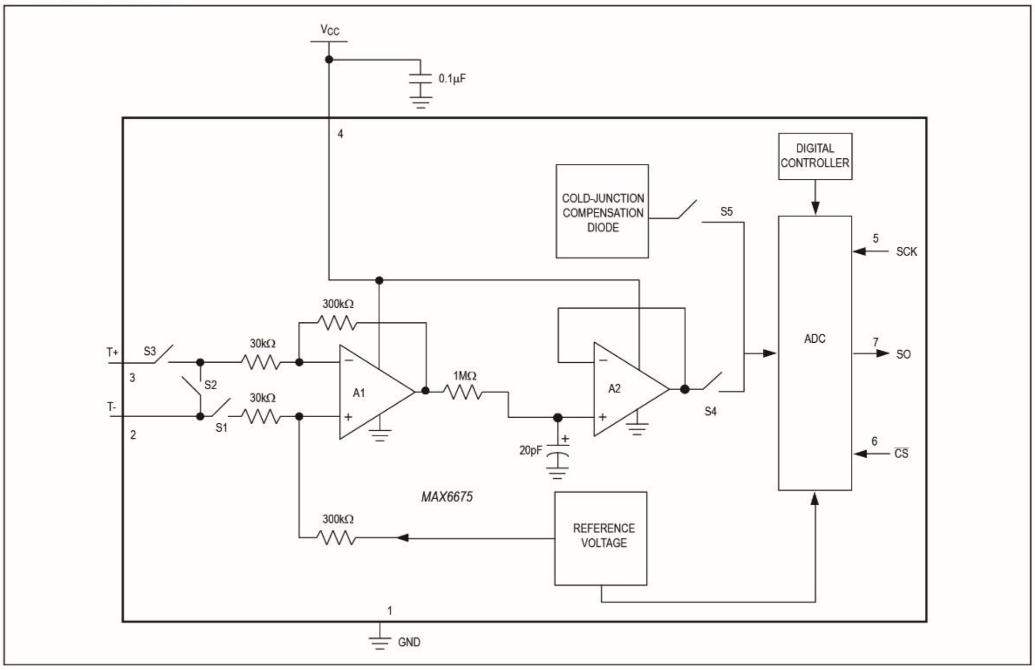


Figure 1b. Serial Interface Timing

BIT	DUMMY SIGN BIT	12-BIT TEMPERATURE READING												THERMOCOUPLE INPUT	DEVICE ID	STATE
Bit	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
	0	MSB											LSB		0	Three-state

Figure 2. SO Output

Block Diagram



Package Information

For the latest package outline information and land patterns (footprints), go to **www.maximintegrated.com/packages**. Note that a "+", "#", or "-" in the package code indicates RoHS status only. Package drawings may show a different suffix character, but the drawing pertains to the package regardless of RoHS status.

PACKAGE TYPE	PACKAGE CODE	OUTLINE NO.	LAND PATTERN NO.
8 SO	S8+2	**21-0041**	**90-0096**

Revision History

REVISION NUMBER	REVISION DATE	DESCRIPTION	PAGES CHANGED
2	4/14	Removed automotive reference	1

Pressure Sensor Datasheet

BD|SENSORS
pressure measurement

30.600 G

OEM Pressure Transmitter Low Cost

Applications

- mechanical and plant engineering
- general industrial applications

Characteristics

- ceramic sensor
- accuracy 1 % FSO according to IEC 60770
- nominal pressure ranges from 0 … 1.6 bar up to 0 … 250 bar

Technical Data

Input pressure range													
Nominal pressure gauge	[bar]	1.6	2.5	4	6	10	16	25	40	60	100	160	250
Overpressure	[bar]	5	5	12	12	20	50	50	120	120	200	400	400
Burst pressure ≥	[bar]	7	7.5	15	18	30	70	75	150	180	300	500	750
Vacuum resistance		unlimited											

Output signal / Supply			
Standard	2-wire: 4 ... 20 mA	/	V_S = 8 ... 32 V_{DC}
Options	3-wire: 0 ... 10 V 3-wire ratiometric: 10 … 90 % of V_S	/ /	V_S = 14 ... 30 V_{DC} V_S = 2.7 ... 5 V_{DC}
Performance			
Accuracy [1]	≤ ± 1 % FSO		
Permissible load	2-wire: $R_{max} = [(V_S - V_{S\,min}) / 0.02\,A]\,\Omega$		3-wire: $R_{min} = 10\,k\Omega$
Influence effects	supply: 0.05 % FSO / 10 V		load: 0.05 % FSO / kΩ
Response time	2-wire: ≤ 10 msec		3-wire: ≤ 3 msec
Long term stability	≤ ± 0.3 % FSO / year at reference conditions		
Measuring rate	1 kHz		
[1] accuracy according to IEC 60770 – limit point adjustment (non-linearity, hysteresis, repeatability)			
Thermal effects (offset and span) / Permissible temperatures			
Thermal error	≤ ± 0.5 % FSO / 10 K (typ.)	in compensated range 0 ... 85 °C	
Permissible temperatures	medium: -25 ... 125 °C	electronics / environment: -25 ... 85 °C	storage: -40 ... 85 °C
Electrical protection			
Short-circuit protection	permanent	3-wire ratiometric: none	
Reverse polarity protection	no damage, but also no function		
Electromagnetic protection	emission and immunity according to EN 61326		
Mechanical stability			
Vibration	10 g, 25 Hz … 2 kHz	according to DIN EN 60068-2-6	
Shock	500 g / 1 msec	according to DIN EN 60068-2-27	

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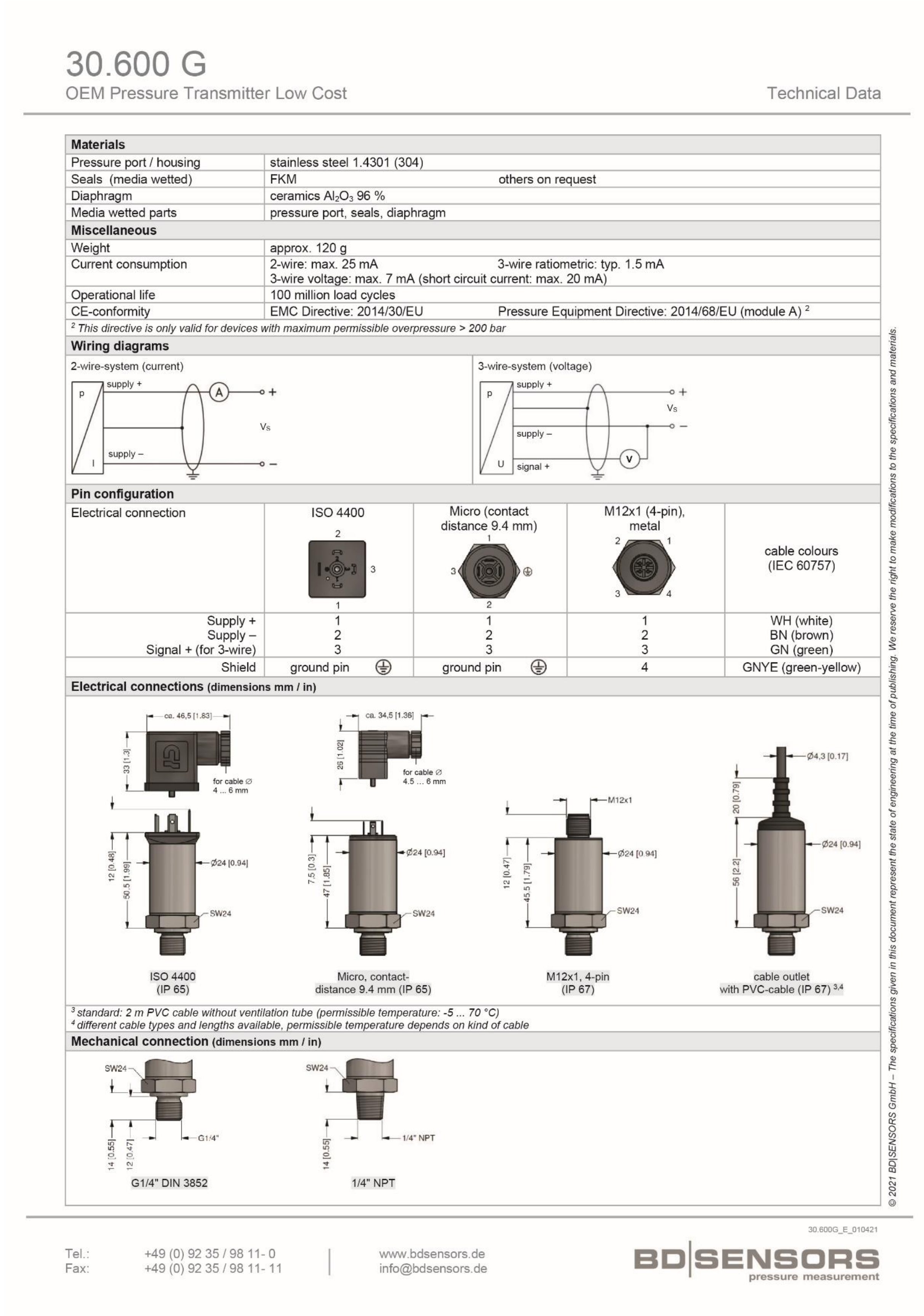
info@bdsensors.de



30.600 G

OEM Pressure Transmitter Low Cost

Technical Data

Materials		
Pressure port / housing	stainless steel 1.4301 (304)	
Seals (media wetted)	FKM	others on request
Diaphragm	ceramics Al_2O_3 96 %	
Media wetted parts	pressure port, seals, diaphragm	
Miscellaneous		
Weight	approx. 120 g	
Current consumption	2-wire: max. 25 mA 3-wire voltage: max. 7 mA (short circuit current: max. 20 mA)	3-wire ratiometric: typ. 1.5 mA
Operational life	100 million load cycles	
CE-conformity	EMC Directive: 2014/30/EU	Pressure Equipment Directive: 2014/68/EU (module A) [2]

[2] *This directive is only valid for devices with maximum permissible overpressure > 200 bar*

Wiring diagrams

2-wire-system (current)

3-wire-system (voltage)

Pin configuration

Electrical connection	ISO 4400	Micro (contact distance 9.4 mm)	M12x1 (4-pin), metal	cable colours (IEC 60757)
Supply +	1	1	1	WH (white)
Supply –	2	2	2	BN (brown)
Signal + (for 3-wire)	3	3	3	GN (green)
Shield	ground pin ⏚	ground pin ⏚	4	GNYE (green-yellow)

Electrical connections (dimensions mm / in)

ISO 4400 (IP 65)

Micro, contact-distance 9.4 mm (IP 65)

M12x1, 4-pin (IP 67)

cable outlet with PVC-cable (IP 67) [3,4]

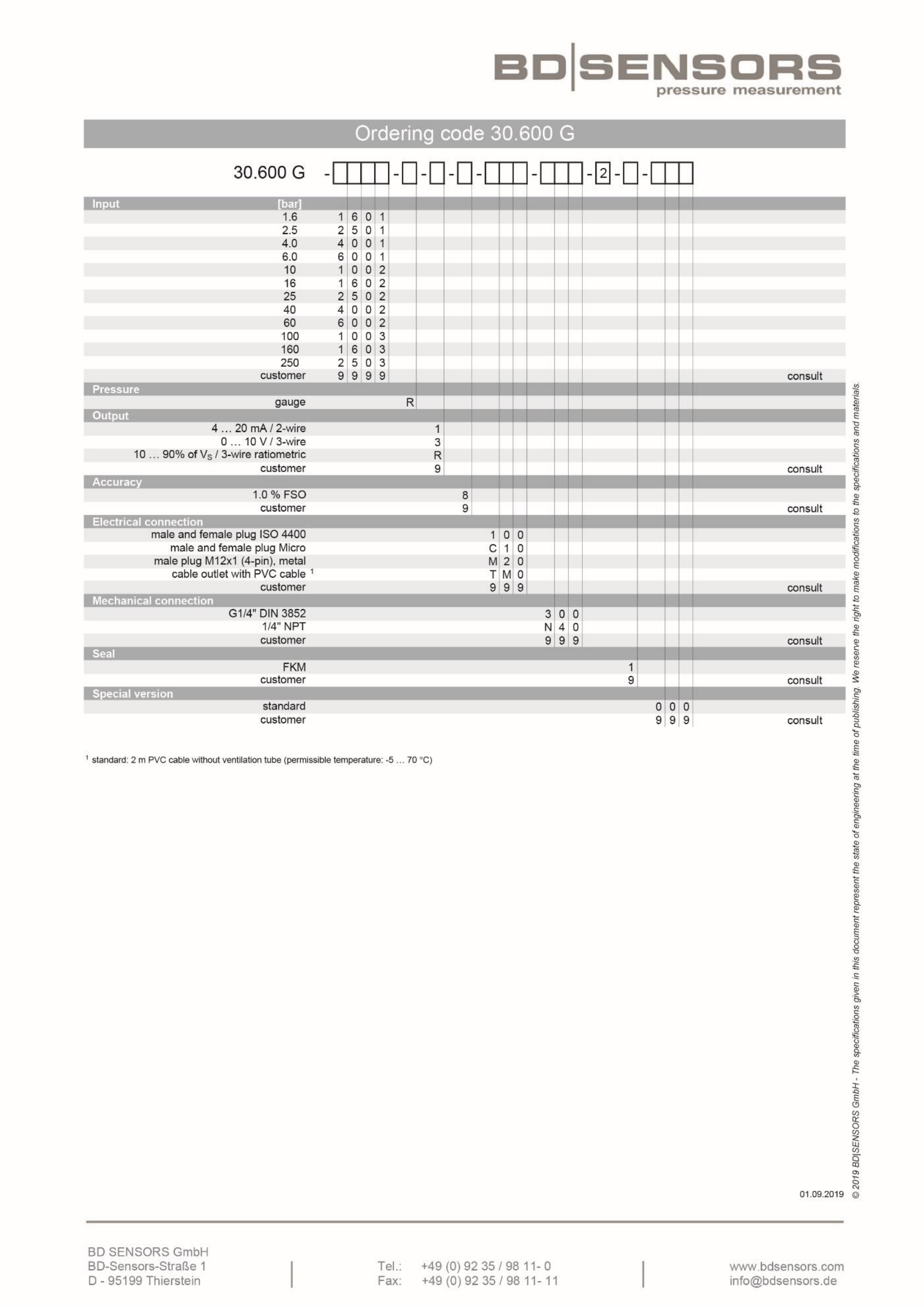
[3] *standard: 2 m PVC cable without ventilation tube (permissible temperature: -5 ... 70 °C)*

[4] *different cable types and lengths available, permissible temperature depends on kind of cable*

Mechanical connection (dimensions mm / in)

G1/4" DIN 3852

1/4" NPT



BD|SENSORS
pressure measurement

Ordering code 30.600 G

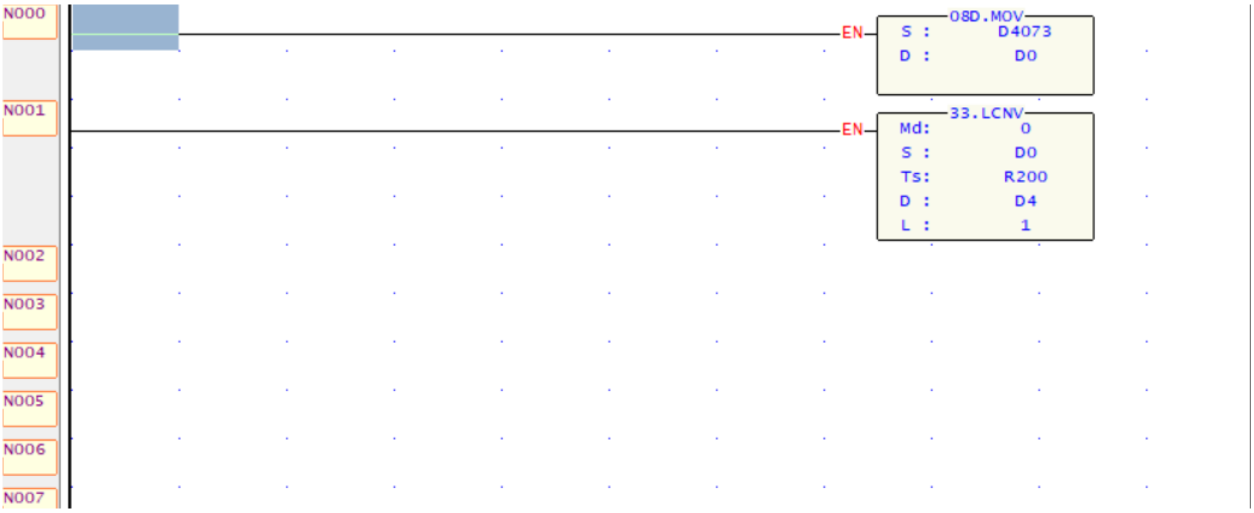
30.600 G - ☐☐☐☐ - ☐ - ☐ - ☐ - ☐☐☐ - ☐☐☐ - 2 - ☐ - ☐☐☐

Input [bar]		
1.6	1 6 0 1	
2.5	2 5 0 1	
4.0	4 0 0 1	
6.0	6 0 0 1	
10	1 0 0 2	
16	1 6 0 2	
25	2 5 0 2	
40	4 0 0 2	
60	6 0 0 2	
100	1 0 0 3	
160	1 6 0 3	
250	2 5 0 3	
customer	9 9 9 9	consult
Pressure		
gauge	R	
Output		
4 … 20 mA / 2-wire	1	
0 … 10 V / 3-wire	3	
10 … 90% of V_S / 3-wire ratiometric	R	
customer	9	consult
Accuracy		
1.0 % FSO	8	
customer	9	consult
Electrical connection		
male and female plug ISO 4400	1 0 0	
male and female plug Micro	C 1 0	
male plug M12x1 (4-pin), metal	M 2 0	
cable outlet with PVC cable [1]	T M 0	
customer	9 9 9	consult
Mechanical connection		
G1/4" DIN 3852	3 0 0	
1/4" NPT	N 4 0	
customer	9 9 9	consult
Seal		
FKM	1	
customer	9	consult
Special version		
standard	0 0 0	
customer	9 9 9	consult

[1] standard: 2 m PVC cable without ventilation tube (permissible temperature: -5 … 70 °C)

01.09.2019

PLC Code (Lader)



```
08D.MOV
S : D4073
D : D0

33.LCNV
Md: 0
S : D0
Ts: R200
D : D4
L : 1
```

Arduino code

```
#include "max6675.h"
int soPin = 4;// DO=Serial Out
int csPin = 2;// CS = chip select CS pin
int sckPin = 9;// CLK = Serial Clock pin
MAX6675 robojax(sckPin, csPin, soPin);
void setup() {
  Serial.begin(9600);
}
void loop() {
   Serial.print("Temp in C = ");
   Serial.print(robojax.readCelsius());
  Serial.print("\t");
  Serial.print("\n");
   Serial.print("Temp in F = ");
   Serial.println(robojax.readFahrenheit());
   Serial.print("\n");
  delay(2000);
  }
```