BASKENT UNIVERSITY
INSTITUTE OF SCIENCE AND ENGINEERING
DEPARTMENT OF MECHANICAL ENGINEERING
MASTER IN MECHANICAL ENGINEERING WITH THESIS

DESIGN AND ANALYSIS OF A HYDRO-PNEUMATIC SUSPENSION SYSTEM

MASTER OF SCIENCE THESIS

BY

CAN KUTAY TUÇ

ANKARA – 2020

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PROF. DR. FARUK ELALDI

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This study, which was prepared by Can Kutay TUÇ, for the program of Mechanical Engineering Master of Degree, has been approved in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE in Mechanical Engineering Department by the following committee.

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Thesis Title : Design and Analysis of a Hydro-Pneumatic Suspension System

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APPROVAL

Prof. Dr. Faruk ELALDI
Director, Institute of Science and Engineering

DATE : … / … / ……

BAŞKENT ÜNİVERSİTESİ
FEN BİLİMLERİ ENSTİTÜSÜ
YÜKSEK LİSANS TEZ ÇALIŞMASI ORİJİNALLİK RAPORU

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Yukarıda başlığı belirtilen Yüksek Lisans tez çalışmamın; Giriş, Ana Bölümler ve Sonuç Bölümünden oluşan, toplam **110** sayfalık kısmına ilişkin, **09/01/2020** tarihinde tez danışmanım tarafından **TURNITIN** adlı intihal tespit programında aşağıda belirtilen filtremeler uygulanarak alınmış olan orijinallik raporuna göre, tezimin benzerlik oranı **%8**'dir.

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Öğrenci İmzası : ……………………

Onay
09 / 01 / 2020

Öğrenci Danışmanı Prof. Dr. Faruk ELALDI

To my family,

ÖZET

Can Kutay TUÇ
HİDROPNÖMATİK SÜSPANSİYON SİSTEMİ TASARIMI VE ANALİZİ
Başkent Üniversitesi Fen Bilimleri Enstitüsü
Makine Mühendisliği Anabilim Dalı
2020

Süspansiyon sistemleri genel olarak, sürüş dinamikleri ve konfor bakımından bir aracın en önemli parçalarından biri olup, araçların, özellikle yüksek tonajlı araçların arazi performansları ve hareket kabiliyetleri de süspansiyon sistemlerine bağlı olarak değişmektedir. Bu tez çalışmasında, ilk olarak hidropnömatik süspansiyon sistemi mekanizmasının pozisyon ve hız denklemleri, daha sonra sistemin parametrik olarak tasarlanabilmesi için gerekli olan sistem giriş ve çıkış parametreleri belirlenerek, bu parametreler ile ilgili gerekli denklemler türetilmiştir. Türetilen parametrik denklemler kullanılarak, farklı konfigürasyonlardaki hidropnömatik sistem tasarımlarının hızlı ve kolay bir şekilde tasarlanmasına olanak sağlayacak kullanıcı arayüz programı geliştirilmiştir. Daha sonra, önceden belirlenen sistem giriş parametreleri ve geliştirilen kullanıcı arayüz programı kullanılarak, hidropnömatik sistem detay tasarımı yapılmış ve sistemin 3 boyutlu katı modeli oluşturulmuştur. Tasarlanan sistemin malzeme listesi, parça ve montaj teknik resimleri hazırlanmıştır. Ayrıca, tasarlanan sisteme en kritik yükleme koşulu altında sonlu elemanlar analizi yapılmış ve sonlu elemanlar analizi sonucu elde edilen veriler ile kullanıcı arayüz programı sonucu elde edilen veriler karşılaştırılmıştır. Son olarak, tasarlanan hidropnömatik süspansiyon sistemi için teknik veri paketi hazırlanmıştır.

ANAHTAR KELİMELER : Süspansiyon, Hidropnömatik süspansiyon, Süspansiyon tasarımı, Parametrik modelleme

ABSTRACT

Can Kutay TUÇ
DESIGN AND ANALYSIS OF A HYDRO-PNEUMATIC SUSPENSION SYSTEM
Baskent University Institute of Science and Engineering
Department of Mechanical Engineering
2020

Suspension systems are generally one of the most critical components for the ride dynamics and comfort performance of a vehicle. Also, off road performance and mobility of the high tonnage vehicles directly depend on the suspension system of the vehicle. In this thesis study, firstly displacement and velocity equations have been derived by using the kinematics of the hydro-pneumatic suspension unit (HSU) mechanism. Furthermore, the input and output parameters have been specified to design an HSU and necessary parametric equations have been derived which related with the input and output parameters. By using the derived equations, a graphical user interface (GUI) has been developed which enables the user to easily design different configurations of an HSU. Then, by using the predetermined input parameters and developed GUI, detailed design of the system and the 3D CAD model of a hydro-pneumatic suspension system have been performed. Bill of materials, manufacturing and assembly drawings have been prepared for the designed system. Also, structural finite element analysis have been performed for the worst case loading conditions of the system and finite element analysis results have been compared with the GUI output results. Finally, technical data package have been prepared for the designed HSU.

KEYWORDS **:** Suspension, Hydro-pneumatic suspension, Suspension design, Parametric modelling

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LIST OF SYMBOLS AND ABBREVIATIONS

X_A	X coordinate of point A
Y_A	Y coordinate of point A
r_2	crank radius
r_3	length of the piston rod
r_c	length of the wheel arm
e	piston offset
h_3	distance between X axis and point 2
h	distance between x axis and wheel center
α	angle between x and X axis
θ_2	angle between X axis and link 2
θ_3	angle between X axis and link 3
θ_{CX}	angle between x axis and wheel arm
θ_{AC}	angle between suspension arm and wheel arm
θ_{23}	angle between link 2 and link 3
X_B	displacement of the hydraulic piston
X_{B0}	displacement of the hydraulic piston at static position
X_{Bi}	instantaneous displacement of the hydraulic piston
V_B	velocity of point B (hydraulic piston)
V_p	instantaneous velocity of the hydraulic piston
V_h	vertical velocity of the wheel axis
P_0	pressure inside the cylinders at static position
P_i	instantaneous pressure inside the cylinders
V_0	gas volume at static position
V_i	instantaneous gas pressure
n	polytrophic index
D_p	piston diameter
A_p	piston area
A_0	orifice area
k_{Pi}	spring coefficient of the gas
Q_i	instantaneous flow rate at the orifice
C_d	discharge coefficient
ΔP	differential pressure
ΔP_{nom}	nominal differential pressure
ΔP_{max}	pressure relief valve set pressure
ρ	density of the hydraulic fluid
c	damping coefficient for viscous damping
$F_{Pspring}$	spring force acting on the hydro-gas piston
$F_{Pdamping}$	viscous damping force acting on the hydraulic piston
F_{Wheel}	wheel reaction force
F_{piston}	longitudinal force acting on the hydraulic piston
$F_{guidering}$	transverse force acting on the hydraulic piston
$F_{Wspring}$	spring force acting on the wheel
$F_{Wdamping}$	viscous damping force acting on the wheel
F_{Wheel}	total force acting on the wheel
$P_{guidering}$	surface pressure on the guide ring

$P_{all.guidering}$ maximum allowable surface pressure on the guide ring
$W_{guidering}$ width of the guide ring
$F_{s.guidering}$ factor of safety for the guide ring

1. INTRODUCTION

Suspension systems are one of the most critical components for the ride dynamics and comfort performance of a vehicle. Also, off road performance and mobility of the high tonnage vehicles directly depend on the suspension system of the vehicle. High tonnage vehicles such as tanks, tracked howitzers and fighting vehicles in military applications generally use two types of suspension systems. Those are torsion bars and hydraulic suspension systems. Most of the tracked military vehicles which require high mobility and off road performance together with comfortableness and speed preferred to use torsion bar suspension systems due to low cost and low maintenance. But, hit accuracy and long term combat requirements brought the necessity of using more comfortable and higher off road performance for these types of vehicles. The solution to these new requirements is found by the hydro-pneumatic suspension systems.

"A suspension system usually consists of a spring and a damper. The spring alone would already allow the decoupling of input side and isolated side just by its elastic properties and would compensate accelerations/displacements from the input side. Yet, due to the displacement, the spring would store energy and therefore the system would keep on oscillating permanently. Not only this, in case of further excitations with suitable frequency and phase, it would pick up further energy and the amplitude on the isolated side would increase even further (resonance). If this happens the result is the exact opposite of the original goal, instead of reducing the accelerations on the isolated side they are amplified above the level without a suspension system. This is why a spring is almost always used in combination with a damper. The energy that has been temporarily stored in the spring is converted into heat by the damper and the amplitude of the oscillation therefore decays. The higher the damping forces, the faster the amplitude will decay, yet the stronger is the direct (non-elastic) coupling of the input side to the isolated side and the input side excitations will be transferred with higher intensity. So to achieve the best possible result from the tuning of a suspension system, there is a lot of experience, intuition and effort (especially testing) necessary. Most commonly used dampers are hydraulic components which use the displacement of internal fluid and the respective viscosity to generate damping forces – the latter are therefore velocity dependent." (Bauer, 2008, Pg. 6) [1]

The linear characteristics of conventional suspension systems limit the mobility, the ride performance and the comfort of tracked vehicles. But the nonlinear characteristics of hydro-pneumatic suspension units (HSU) provide better performance in above mentioned parameters. Also HSU have superior damping performance and compact designs. For that reasons the HSUs not only increases the mobility, ride performance and comfort, but also significantly increase the weapon system accuracy for armored fighting vehicles by providing more stable gun platform compared to conventional suspension systems.

As a result, in tracked vehicle applications hydro-pneumatic suspension units are preferred due to its advantages on conventional suspension systems.

1.1. Scope of Work

There are two main purposes of this study; first one is to derive displacement and velocity equations by parametric modelling to the system for developing a graphical user interface (GUI) to easily design different configurations of an HSU. The second one is to design an HSU by using the developed GUI and prepare a technical data package for that HSU.

The necessary equations and input-output parameters have been derived. By using the derived equations, a GUI has been developed in “MATLAB-App Designer” to provide output parameters for designing a hydro-pneumatic suspension system.

By using the predetermined input parameters and developed GUI, detailed design and the 3D CAD model of a hydro-pneumatic suspension system have been performed. Then, bill of materials, manufacturing and assembly drawings have been prepared for the designed system. Furthermore; structural finite element analysis has been performed for the worst case loading conditions of the system and finite element analysis results have been compared with the GUI output results. Finally, technical data package have been prepared for the designed HSU. The typical view of HSUs on a tracked vehicle and the front, left, top and isometric views of the designed HSU have been shown in Figure 1.1 and Figure 1.2 respectively.

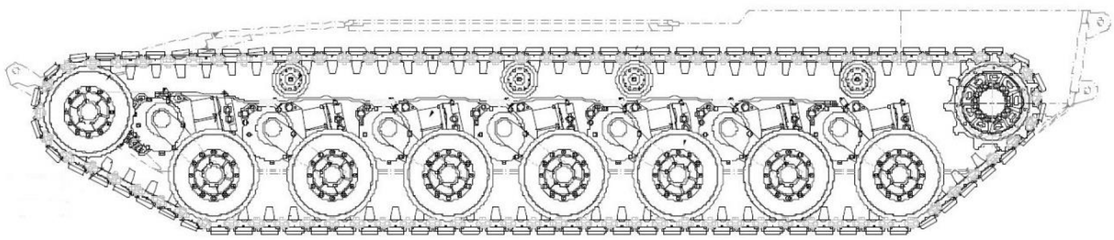


Figure 1.1 Typical view of HSUs on a tracked vehicle [2]

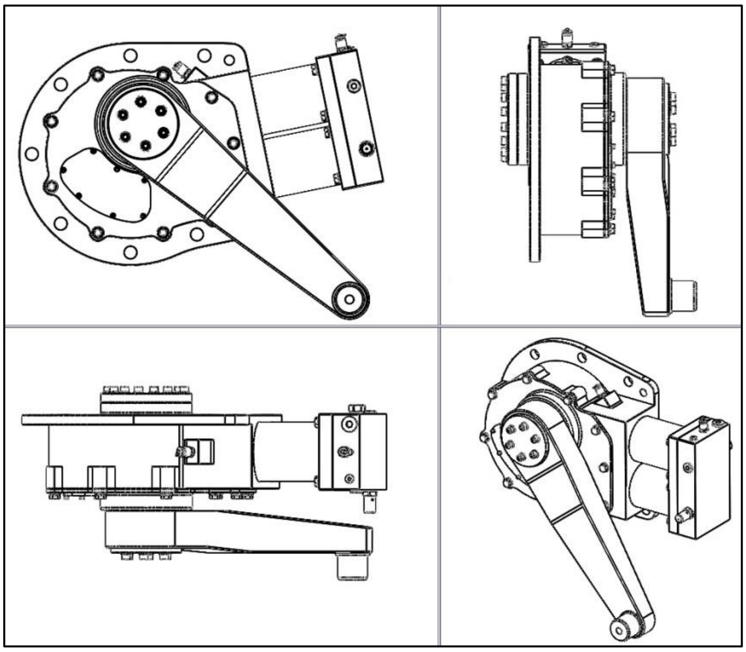


Figure 1.2 Front, left, top and isometric views of the designed HSU

2. LITERATURE REVIEW

S. Sridhar and N.S. Sekar have been published an article about optimization of kinematics of hydro-pneumatic suspension units used in tracked vehicles. It is known that the sealing performance of the piston seals is one of the most important issues for the system reliability. The optimization methods for minimizing the transverse force on the piston seals which are, shifting and reorienting the cylinder axis and determination of the load transfer factor, have been explained in detail in the study of S. Sridhar and N.S. Sekar. The kinematic arrangement of a hydro-pneumatic suspension has been shown in Figure 2.1. Also, the transverse force acting on the hydraulic piston for the cases; non-shifted and non-reoriented cylinder axis, shifted but non-reoriented cylinder axis, shifted and reoriented cylinder axis have been shown in Figure 2.2, Figure 2.3 and Figure 2.4 respectively. [2]

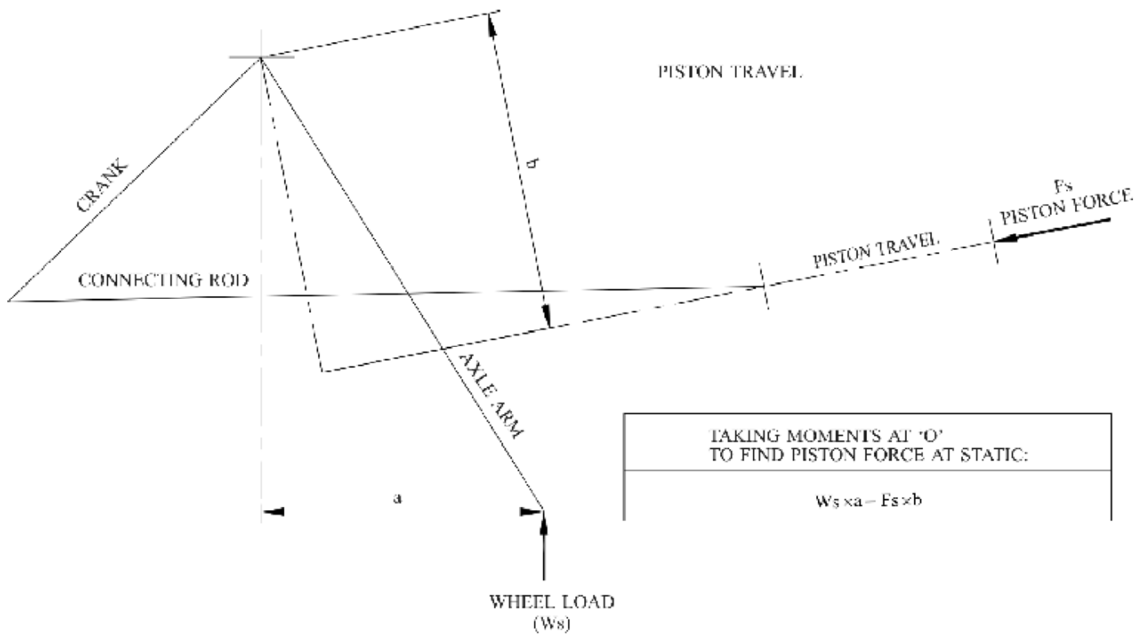


Figure 2.1 Kinematic arrangement of a hydro-pneumatic suspension [2]

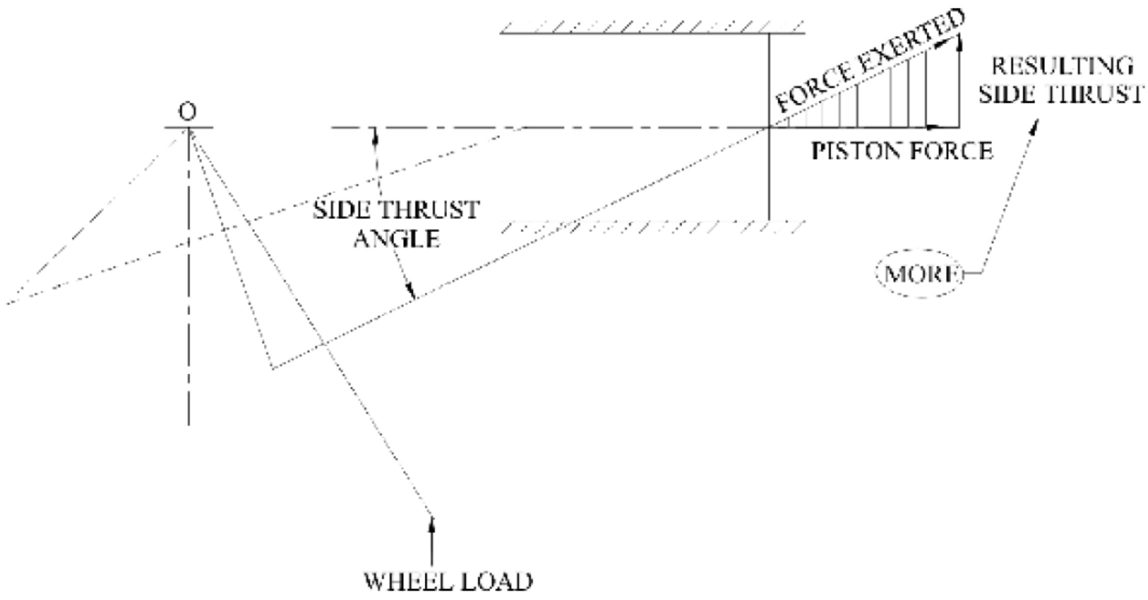


Figure 2.2 Transverse force acting on the hydraulic piston for, non-shifted and non-reoriented cylinder axis [2]

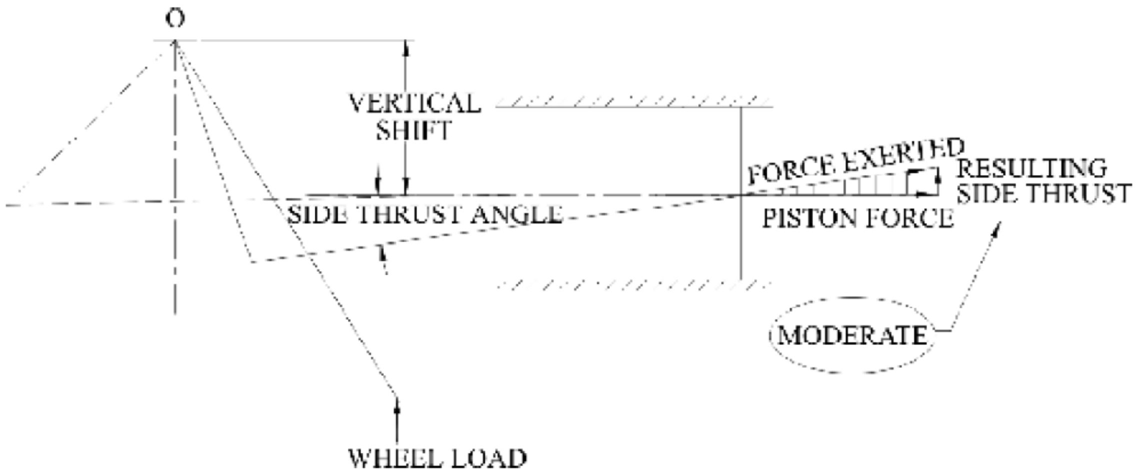


Figure 2.3 Transverse force acting on the hydraulic piston for, shifted but non-reoriented cylinder axis [2]

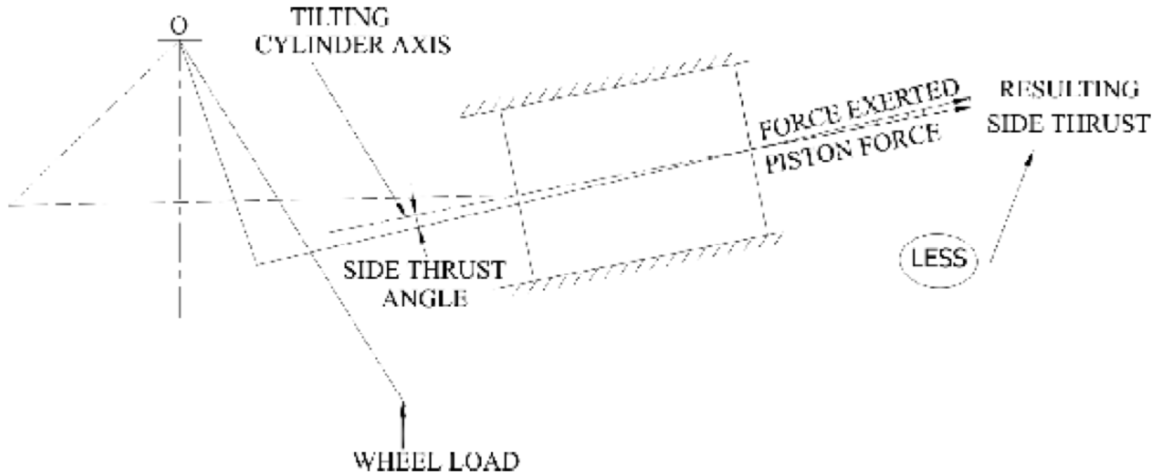


Figure 2.4 Transverse force acting on the hydraulic piston for, shifted and reoriented cylinder axis [2]

U. Solomon and Chandramouli Padmanabhan have published an article about mathematical modelling of a hydro-pneumatic suspension units used in tracked vehicles. In this paper, the spring characteristics of a hydro-pneumatic suspension have been represented by using the polytrophic gas compression model and the orifices have been modeled by using the hydraulic conductance. Moreover, the analytical models have been validated by experiments. The sketch view of the mechanism has been shown in Figure 2.5 and force – displacement graph for analytical model results and experimental results have been shown in Figure 2.6. The force acting on the wheel has been computed by using equation (2.1) where, F_{pi} is piston reaction force and W_{Li} is wheel reaction force. [3]

$$W_{Li} = \frac{F_{pi} \cdot e}{L_{Wi}} \tag{2.1}$$

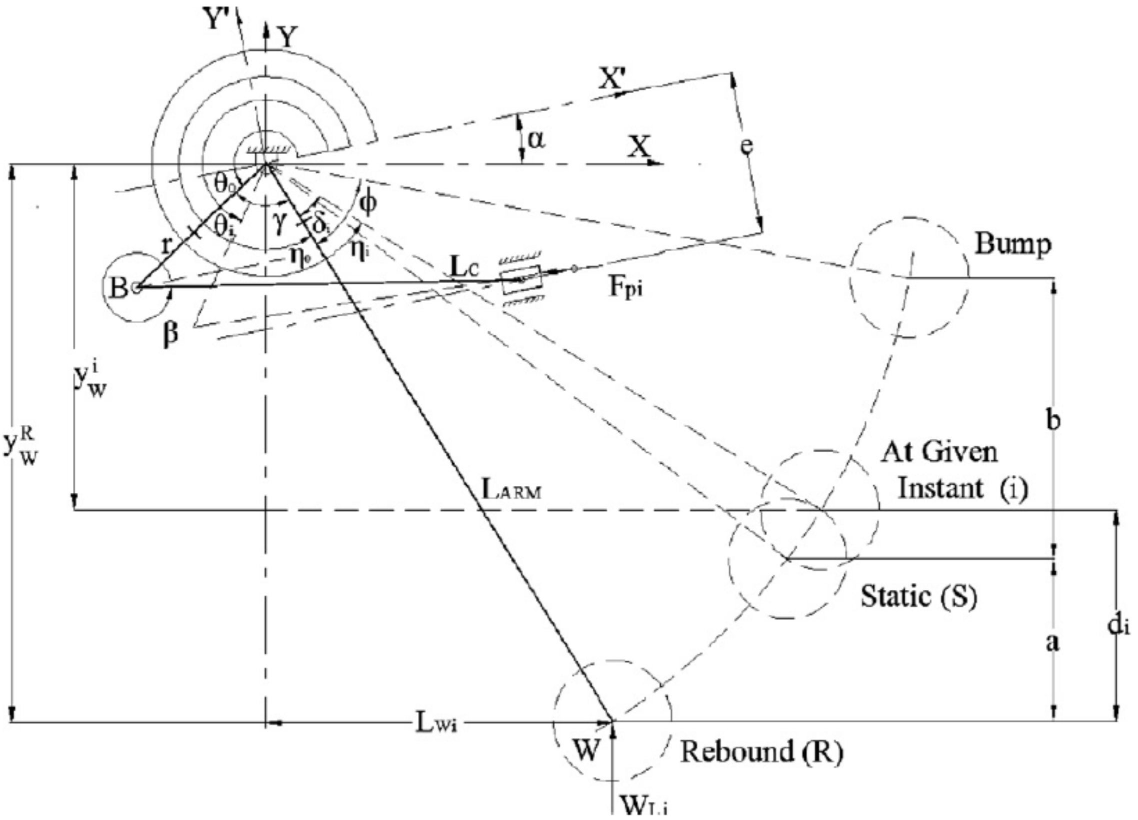


Figure 2.5 Modified Slider Crank Mechanism [3]

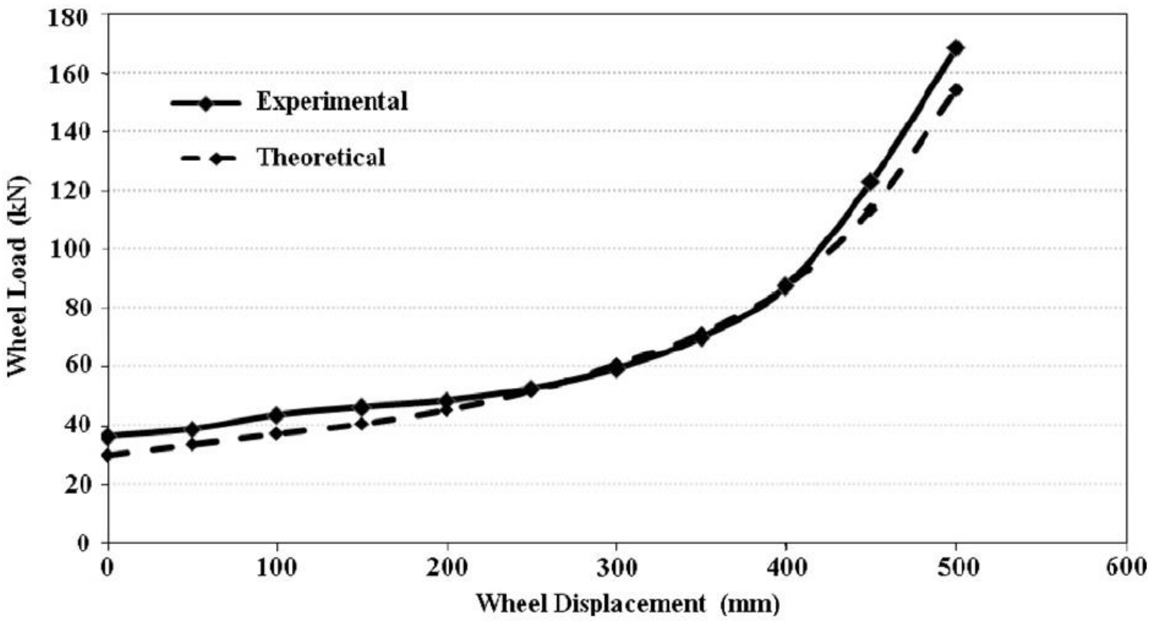


Figure 2.6 Experimental and theoretical force – displacement graph [3]

H. A. Hammad, A. M. Salem, I. Saleh Mostafa, I. A. Elsherif have carried out theoretical and experimental studies on hydro-pneumatic suspension units. A mathematical model has been developed and the developed mathematical model has been validated by using MATLAB-SIMULINK. [4]

Gao Xiaodong, Gu Liang, Guan Jifu, Gao Junfeng have published an article about in-arm suspension units (ISU). In this article, the growth and the ISU products of three companies, which are producing the ISU’s in mass production, have been introduced. Also, the working principles, the main characteristics and application fields of the ISU’s have been discussed in this paper. [5]

Saayan Banerjee, V. Balamurugan, R. Krishnakumar have published an article about development of single station representation of a hydro-pneumatic suspension. The nonlinear stiffness characteristics of the system have been derived by using the kinematics of the hydro-pneumatic suspension system. Then, the equations of motion have been derived for the system and the equations have been solved by using MATLAB. Moreover, ride dynamics of the suspension have been analyzed and validated by using MSC ADAMS. With the help of the mathematical model developed in this study; vibration characteristic of the vehicle has been estimated. [6]

GUO Huaping and LI Ning have published an article about tracked vehicle suspension system growth for military application. In this article; active suspension and semi-active suspension is explained. Moreover, improvement of the suspension system for the military tracked vehicle is explained. [7]

M. K. Ravishankar and C. Sujatha have worked on comparison of torsion bar suspension and hydro-pneumatic suspension systems. Constant stiffness passive suspension system and variable stiffness hydro-gas suspension have been compared on known profile at different speeds. Although, root mean square (RMS) body bounce accelerations have been decreased while the speed decreased for both system; it is observed 50-60% more decreasing RMS body bounce accelerations on the hydro-gas suspension system than passive suspension system. For the other parameters, such as body bounce displacements, similar reduction rates have been observed because of the variable stiffness characteristics of the hydro-gas suspension system. Therefore, hydro-gas suspension system is preferable for military tracked vehicle. [8]

Ganesh Vijaykumar Kinagi, Syam Prasad Pitchuka and Dnyanesh Sonawane, have worked about light military tracked vehicle. They have described the design parameters for hydro-pneumatic suspension of a military tracked vehicle. The required and important parameters are highlighted. Analytical modeling of a hydro-pneumatic suspension has been described to find spring and damping characteristics. It is seen that leverage ratio is very important parameter to identify initial gas volume and maximum gas pressure. Moreover, when the wheel motion frequency is increasing, the damping force also increases. [9]

Jin-Rae Cho, Hong-Woo Lee and Wan-Suk Yoo have worked about damping characteristics of the tracked vehicle hydro-pneumatic suspension unit. It is found that wheel motion frequency and orifice diameter affect the damping performance and gas spring force. When frequency is increasing, damping force is also increasing. Moreover, the damping force is increasing with the decreasing orifice diameter. However, the gas spring force is decreasing with the decreasing orifice diameter and increasing frequency. [10]

3. PARAMETRIC MODELLING OF THE SYSTEM

3.1. Introducing the HSU

The main components of the HSU are; stationary casing, suspension arm, piston rod, wheel arm and sliding pistons (hydraulic piston and hydro-gas piston). System is fixed from the stationary casing. Road wheel is assembled to the wheel arm by using the wheel mounting hub. The vertical movement of the road wheel leads to rotate the suspension arm from the joint axes with the suspension arm. Thus, rotary motion of wheel arm is converted to linear displacement of hydraulic piston. The hydraulic oil inside the hydraulic cylinder flows through the hydraulic block assembly to the hydro-gas cylinder. As a result, the gas inside of the gas chamber is being compressed.

The main components and the layout of the designed HSU have been shown in Figure 3.1 and Figure 3.2 respectively.

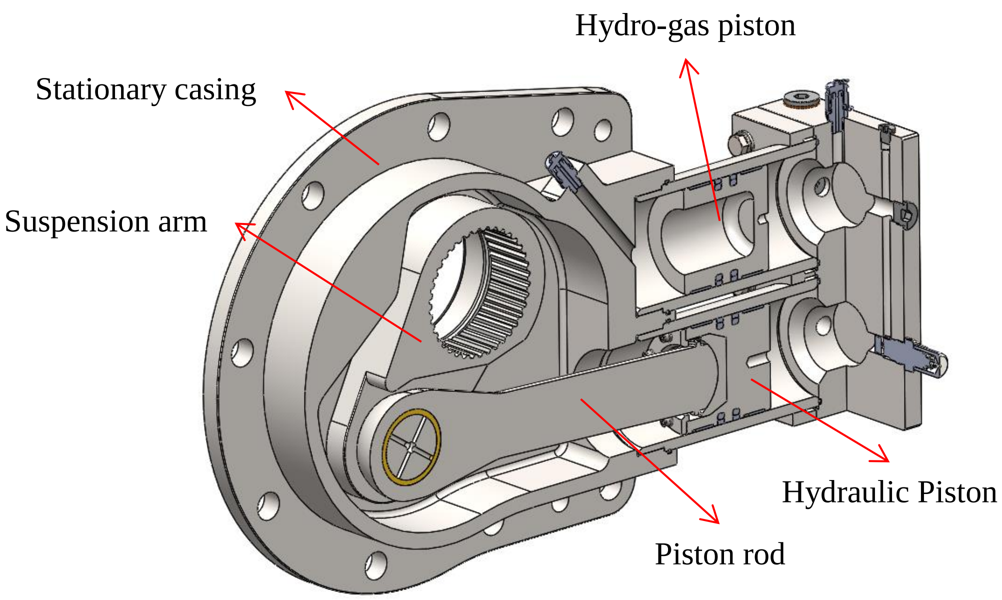


Figure 3.1 Main components of the HSU

The developed HSU have been analyzed in three sections. The first section is the kinematics of the system which is a four bar slider crank mechanism. It is important to configure the kinematics with suitable linkage arrangement considering the mechanism limits, volumetric restrictions and loading conditions of the HSU.

The second section is spring characteristics of the system. Rather than the mechanical spring used in conventional suspension systems, nitrogen gas is used as a spring medium in HSU. By usage of nitrogen gas as a spring, the spring characteristics (spring rate) of the system changes nonlinearly with the upward and downward travel of the wheel. The suspension is soft and spring rate is less for low distance travels of the wheel. However, for high distance travels of the wheel, spring rate increases dramatically thanks to nonlinear characteristics of gas. This provides better ride performance, comfort and mobility for the system in normal conditions. System can also supply required forces for gun recoiling and off road usage.

The last section is the damper characteristics of the system. Hydraulic oil, valves and orifice have been used to provide required viscous damping forces for the system.

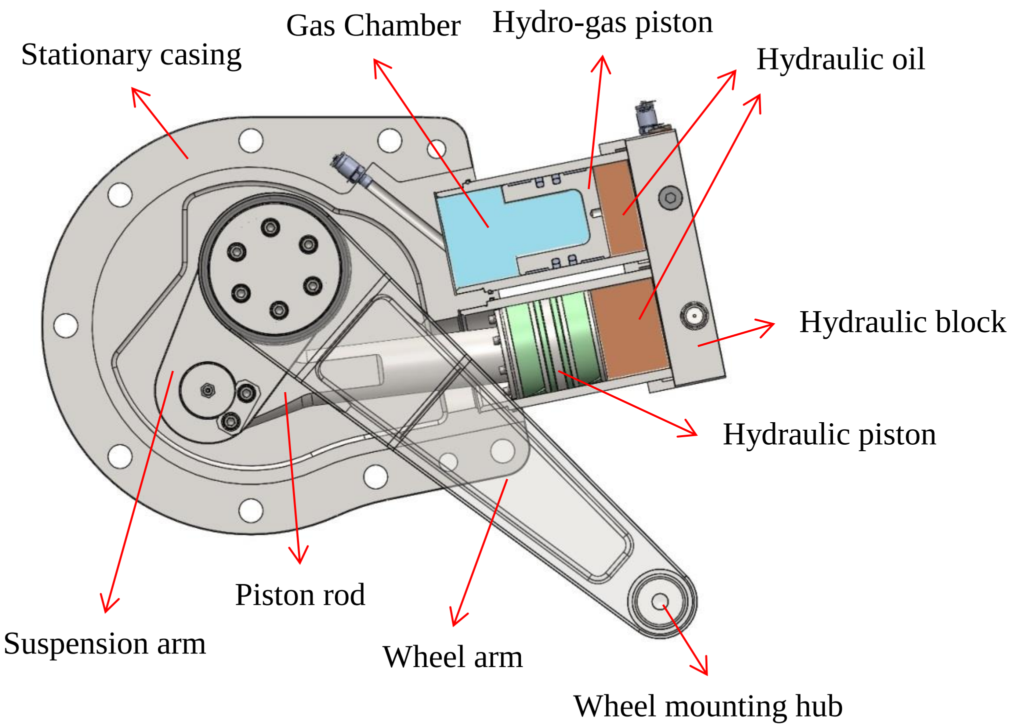


Figure 3.2 Layout of the HSU

In this chapter, input and output parameters have been specified for designing a HSU, parametric equations have been derived individually as a function of input parameters for kinematics, spring characteristics and damper characteristics of the system respectively. Finally, the combined kinematic, spring and damper characteristics of the system have been performed.

3.2. Input and Output Parameters of the System

Input parameters which are required to begin for designing a HSU are as follows;

- mechanism linkages
- rebound, static and bump positions of the wheel axis

- maximum axle arm velocity in terms of the vertical velocity of wheel
- static wheel load and maximum wheel load
- piston diameter (the diameter of hydraulic piston and hydro-gas piston are equal)
- discharge coefficient of orifice
- density of hydraulic oil
- orifice diameter
- pressure relief valve set pressure

Output parameters of the HSU which are derived by using input parameters are as follows;

- maximum piston force
- piston (gas) pressure at static position
- maximum piston (gas) pressure
- total piston stroke
- required dead volume of hydro-gas piston
- maximum velocity of the pistons
- maximum flow rate of the hydraulic fluid

Furthermore, the equations for position, velocity, pressures and forces have been computed as a function of input parameters.

3.3. Kinematics of the System

The kinematic arrangement shown in Figure 3.3 represents the slider crank mechanism for the HSU which converts rotary motion of axle arm into linear piston displacement.

Design and optimization of mechanism have been carried out by taking into consideration space restrictions, wheel displacement limits (rebound and bump positions of the wheel axis), forces acting on links for static and dynamic conditions. Moreover, the radial forces acting on the hydraulic piston seals have been considered, because sealing performance of the piston seals play critical role for the HSU. Leakage in pistons may lead to failure of the HSU. To increase the sealing performance and life of the seals, radial loads on hydraulic piston seals have been minimized by suitable design of the linkage mechanism and changing the orientation of axis of the cylinder.

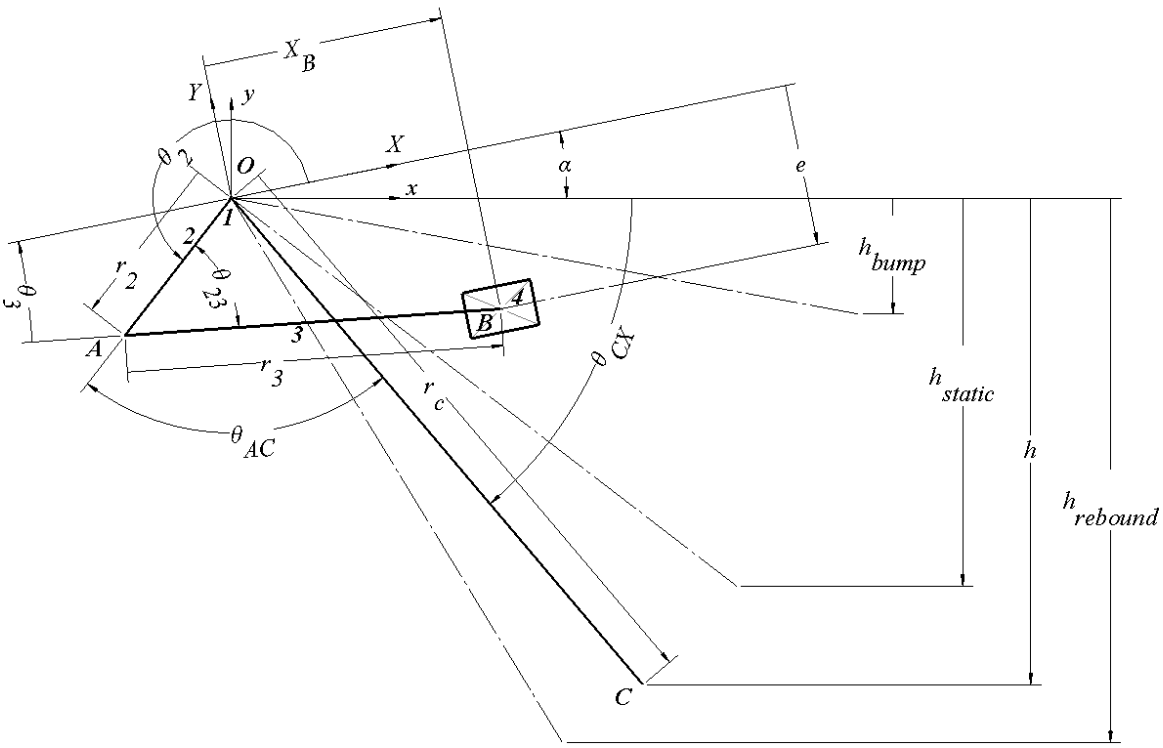


Figure 3.3 Sketch of the mechanism

Kinematic analysis has been carried out to find out the displacement and the velocity of the hydraulic piston as a function of linear velocity and displacement of the wheel axis. The coordinates of point A can be written as,

$$X_A = r_2 \cdot \cos(\theta_2) \ ; \ Y_A = r_2 \cdot \sin(\theta_2)$$

Also it can be written by using geometry,

$$r_2 \cdot \sin(\theta_2) = r_3 \cdot \sin(\theta_3) - e$$

Rearranging the above equation yields,

$$\sin(\theta_3) = \frac{1}{r_3}(e + r_2 \cdot \sin(\theta_2)) \tag{3.1}$$

By using Figure 3.3 the displacement of the hydraulic piston (X_B) can be written as;

$$X_B = r_2 \cdot \cos(\theta_2) + r_3 \cdot \cos(\theta_3) \tag{3.2}$$

It is known that from trigonometry,

$$(\cos(\theta_3))^2 + (\sin(\theta_3))^2 = 1$$

Than $\cos(\theta_3)$ can be written as,

$$\cos(\theta_3) = \mp\sqrt{1-(\sin(\theta_3))^2} \tag{3.3}$$

Substituting equation (3.1) into equation (3.3) and rearranging the equation,

$$\cos(\theta_3) = \mp\frac{1}{r_3}\sqrt{(r_3)^2-(e+r_2\cdot\sin(\theta_2))^2}$$

It is known that from Figure 3.3; $\cos(\theta_3) > 0$ then,

$$\cos(\theta_3) = \frac{1}{r_3}\sqrt{(r_3)^2-(e+r_2\cdot\sin(\theta_2))^2} \tag{3.4}$$

By substituting equation (3.4) into equation (3.2) and rearranging, displacement of the hydraulic piston can be determined as follows;

$$X_B = r_2\cdot\cos(\theta_2)+\sqrt{(r_3)^2-(e+r_2\cdot\sin(\theta_2))^2} \tag{3.5}$$

Taking the derivative of the equation (3.5) with respect to time yields to velocity of the hydraulic piston;

$$\frac{dX_B}{dt} = -r_2\cdot\sin(\theta_2)\cdot\frac{d\theta_2}{dt}-\frac{(e+r_2\cdot\sin(\theta_2))\cdot r_2\cdot\cos(\theta_2)\cdot\frac{d\theta_2}{dt}}{\sqrt{(r_3)^2-(e+r_2\cdot\sin(\theta_2))^2}} \tag{3.6}$$

Note that,

$$\frac{dX_B}{dt} = \dot{X_B} = V_B \; and \; \frac{d\theta_2}{dt} = \dot{\theta}_2$$

Substituting V_B and $\dot{\theta}_2$ into equation (3.6);

$$V_B = -r_2\cdot\sin(\theta_2)\cdot\dot{\theta}_2-\frac{(e+r_2\cdot\sin(\theta_2))\cdot r_2\cdot\cos(\theta_2)\cdot\dot{\theta}_2}{\sqrt{(r_3)^2-(e+r_2\cdot\sin(\theta_2))^2}} \tag{3.7}$$

Equations (3.5) and (3.7) are the equations which show displacement and velocity of the hydraulic piston respectively. Note that the variables in these equations are the angle of link 2 with respect to the X coordinate (θ_2) and the angular velocity of link 2 ($\dot{\theta}_2$). However, it was aimed to derive these equations as a function of position (h) and vertical velocity of the wheel axis (V_h). Therefore the angle of link 2 with respect to the X coordinate (θ_2) and the angular velocity of link 2 ($\dot{\theta}_2$) must be written as a function of position and velocity of the wheel axis.

From geometry, the position of the wheel axis can be written as;

$$h = r_c \cdot \sin(\theta_{CX}) \rightarrow \theta_{CX} = asin\left(\frac{h}{r_c}\right) \tag{3.8}$$

Also the angle of link 2 with respect to the X coordinate can be written as;

$$\theta_{CX} = 2\pi - \alpha - \theta_2 - \theta_{AC} \tag{3.9}$$

Combining and rearranging the equations (3.8) and (3.9), the angle of link 2 with respect to the X coordinate can be written as a function of position of the wheel axis.

$$\theta_2 = 2\pi - \alpha - \theta_{AC} - asin\left(\frac{h}{r_c}\right) \tag{3.10}$$

By taking the derivative of the equation (3.10) with respect to time, the angular velocity of link 2 can be computed as a function of vertical velocity of the wheel axis.

$$\dot{\theta}_2 = \frac{-\dot{h}}{r_c \cdot \sqrt{1 - \left(\frac{h}{r_c}\right)^2}} \tag{3.11}$$

Substituting θ_2 into equation (3.5) and rearranging the equation, displacement of the hydraulic piston can be computed as a function of position of the wheel axis.

$$X_B = r_2 \cdot \cos\left(2\pi - \alpha - \theta_{AC} - asin\left(\frac{h}{r_c}\right)\right) + \sqrt{(r_3)^2 - \left(e + r_2 \cdot \sin\left(2\pi - \alpha - \theta_{AC} - asin\left(\frac{h}{r_c}\right)\right)\right)^2} \tag{3.12}$$

Substituting θ_2 and $\dot{\theta}_2$ into equation (3.7) and rearranging the equation, velocity of the hydraulic piston can be computed as a function of vertical velocity of the wheel axis. (Note that $\dot{h} = V_h$ and $\dot{X}_B = V_B$)

$$V_B = \left[\sin\left(2\pi - \alpha - \theta_{AC} - asin\left(\frac{h}{r_c}\right)\right)\right.$$

$$\left. + \frac{\left(e + r_2 \cdot \sin\left(2\pi - \alpha - \theta_{AC} - asin\left(\frac{h}{r_c}\right)\right)\right) \cdot \cos\left(2\pi - \alpha - \theta_{AC} - asin\left(\frac{h}{r_c}\right)\right)}{\sqrt{r_3^2 - \left[e + r_2 \cdot \sin\left(2\pi - \alpha - \theta_{AC} - asin\left(\frac{h}{r_c}\right)\right)\right]^2}}\right]$$

$$\cdot r_2 \cdot \frac{V_h}{r_c \cdot \sqrt{1 - \left(\frac{h}{r_c}\right)^2}} \tag{3.13}$$

As a result, the displacement and the velocity of the hydraulic piston as a function of linear velocity and vertical displacement of the wheel axis have been computed in equations (3.12) and (3.13).

3.4. Spring Characteristics of the System

The spring characteristics of the system are specified by the pressure of nitrogen gas inside the gas chamber. Displacement of the hydro-gas piston leads to compression and expansion of nitrogen gas inside the gas cylinder. During the compression and expansion of nitrogen gas, it has been assumed that nitrogen gas follows a polytrophic process due to rapid compression or expansion of gas when HSU is working. Thus, spring characteristics of the system change nonlinearly and increase progressively by the increasing displacement of the hydro-gas piston. The detailed view of the hydro-gas piston has been shown in Figure 3.4.

The equations related to spring characteristics of a HSU have been derived. Finally hydro-gas piston pressure and piston force have been computed as a function of the position of the wheel axis.

For polytrophic process, the ideal gas law can be written as;

$$P_i \cdot V_i^n = P_0 \cdot V_0^n$$

Instantaneous gas pressure in the hydro-pneumatic cylinder (P_i) can be written as;

$$P_i = P_0 \cdot \frac{V_0^n}{V_i^n} \tag{3.14}$$

Also instantaneous gas volume inside the hydro-pneumatic cylinder (V_i) can be written as;

$$V_i = V_0 - A_p(X_{Bi} - X_{B0}) \tag{3.15}$$

Substituting the equation (3.15) into equation (3.14) yields;

$$P_i = P_0 \cdot \frac{V_0^n}{\left[V_0 - A_p(X_{Bi} - X_{B0})\right]^n} \tag{3.16}$$

Also it is known that;

$$F_{Pspring} = P_i \cdot A_P \tag{3.17}$$

Substituting equation (3.16) into equation (3.17), the instantaneous piston spring force of the hydro-gas piston as a function of the wheel position can be written as:

$$F_{Pspring} = P_0 \cdot \frac{V_0^n}{\left[V_0 - A_p(X_{Bi} - X_{B0})\right]^n} \cdot A_P$$

The spring coefficient of the gas can be written as;

$$k_{Pi} = \frac{F_{Pspring}}{X_{Bi} - X_{B0}}$$

Note that, V_0, X_{B0} and P_0 are the initial conditions and can be calculated by using the input parameters.

As a result, the equation has been derived which gives the piston force as a function of the vertical displacement of the wheel axis.

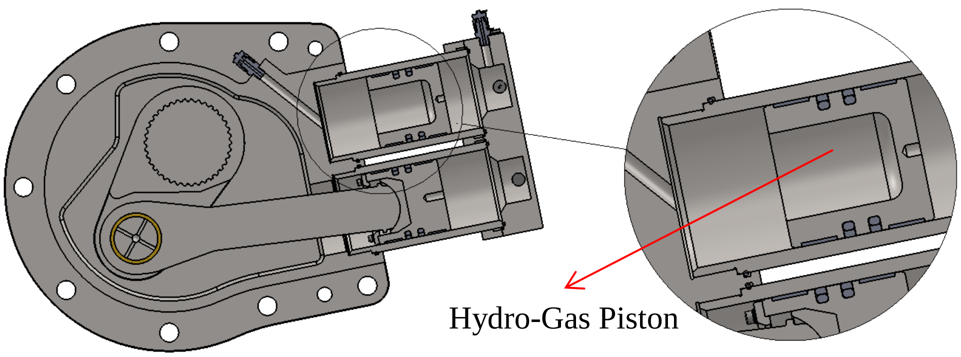


Figure 3.4 Detailed view of hydro-gas piston

3.5. Damper Characteristics of the System

The hydraulic section of the system works as a damper. Figure 3.5 shows the hydraulic circuit diagram of the HSU. There are two cylinders which have in-parallel oriented to each other. The first cylinder is a hydraulic cylinder filled with hydraulic oil. The second cylinder is a hydro-pneumatic cylinder which is filled with nitrogen gas and hydraulic oil at the same time. Nitrogen gas and hydraulic oil are separated from each other with hydro-gas piston.

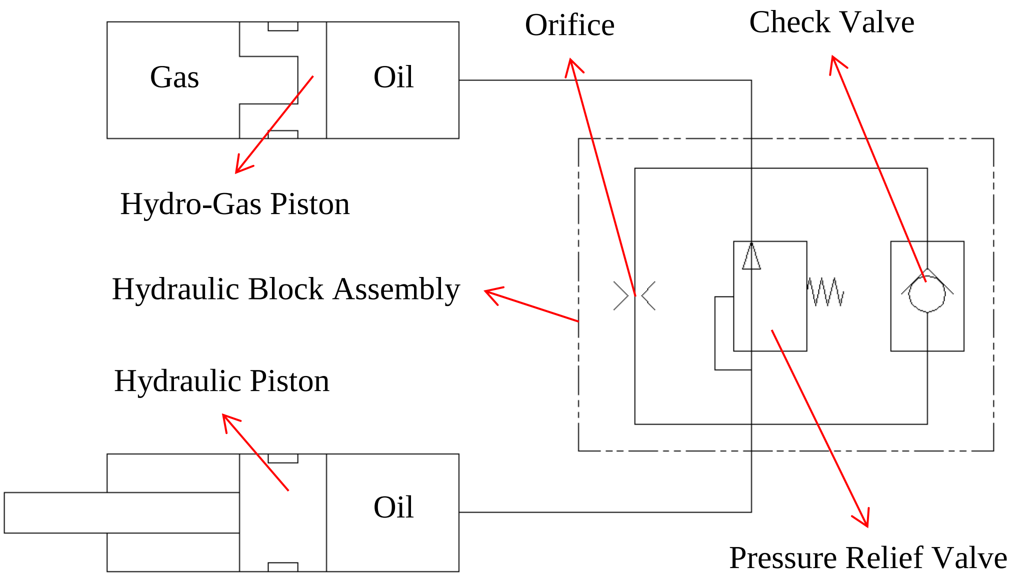


Figure 3.5 Hydraulic circuit diagram

For upward motion of the wheel, the hydraulic oil passes from hydraulic cylinder to hydro-pneumatic cylinder through the hydraulic block assembly which compresses the gas inside the gas chamber. The fluid flow inside the hydraulic block is restricted with an orifice. Pressure difference between the inlet and the outlet of the orifice generates the viscous damping force. The force generated by the orifice is proportional to the vertical velocity of the wheel. Therefore, increasing the vertical velocity of the wheel leads to increase the damping force linearly. But for high vertical velocities of the wheel, pressure difference between the inlet and the outlet of the orifice increases dramatically. To protect the system from excessive pressures and damping forces, pressure relief valve have been assembled to the hydraulic block assembly. When the pressure difference exceeds the set pressure of the pressure relief valve, spool of the pressure relief valve opens and discharges the over pressure to the hydro-pneumatic cylinder.

For downward motion of the wheel, process is reversed. The compressed gas in the gas chamber forces the hydro-gas piston and hydraulic oil flows freely through the check valve into the hydraulic cylinder side. So the wheel moves quickly and freely into the downward position.

The equations related to damper characteristics of a HSU have been derived and finally damping force has been computed as a function of the vertical velocity of the wheel axis.

The instantaneous flow rate at the orifice can be written as;

$$Q_i = A_p \cdot V_p \tag{3.18}$$

Also the instantaneous flow rate through the orifice can be written in another way as follows,

$$Q_i = C_d \cdot A_0 \sqrt{\frac{2 \cdot \Delta P}{\rho}} \tag{3.19}$$

Equating the equations (3.18) and (3.19) yields;

$$A_p \cdot V_p = C_d \cdot A_0 \sqrt{\frac{2 \cdot \Delta P}{\rho}} \tag{3.20}$$

Rearranging the equation (3.20), differential pressure at the orifice can be written as;

$$\Delta P_{nom} = \frac{\rho \cdot A_p^2 \cdot V_p^2}{2 \cdot C_d^2 \cdot A_0^2} \tag{3.21}$$

Note that, the differential pressure is limited by the pressure relief valve set pressure, so the differential pressure must be less than or equal to the set pressure of the pressure relief valve.

If $\quad \Delta P_{nom} \leq \Delta P_{max} \;\rightarrow\; \Delta P_{nom} = \Delta P$

Else, $\quad \Delta P_{nom} \geq \Delta P_{max} \;\rightarrow\; \Delta P_{max} = \Delta P$

Where ΔP_{max} is set pressure of the pressure relief valve, so the damping force of the hydraulic piston can be written as;

$$F_{Pdamping} = c \cdot V_p = A_p \cdot \Delta P \tag{3.22}$$

By substituting equation (3.21) into (3.22) and rearranging the equation, the damping coefficient can be written as;

$$c = \frac{\rho \cdot A_p^3 \cdot V_p}{2 \cdot C_d^2 \cdot A_0^2}$$

As a result, the equation have been derived which gives the damping force of the piston as a function of the vertical velocity of the wheel axis.

3.6. Combined Kinematic, Spring and Damper Characteristics

Viscous damping force and spring force equations have been reflected to the wheel by using the kinematics of the HSU. Free body diagrams (FBD) for the links of the mechanism have been drawn, which are shown in Figure 3.6, Figure 3.7 and Figure 3.8.

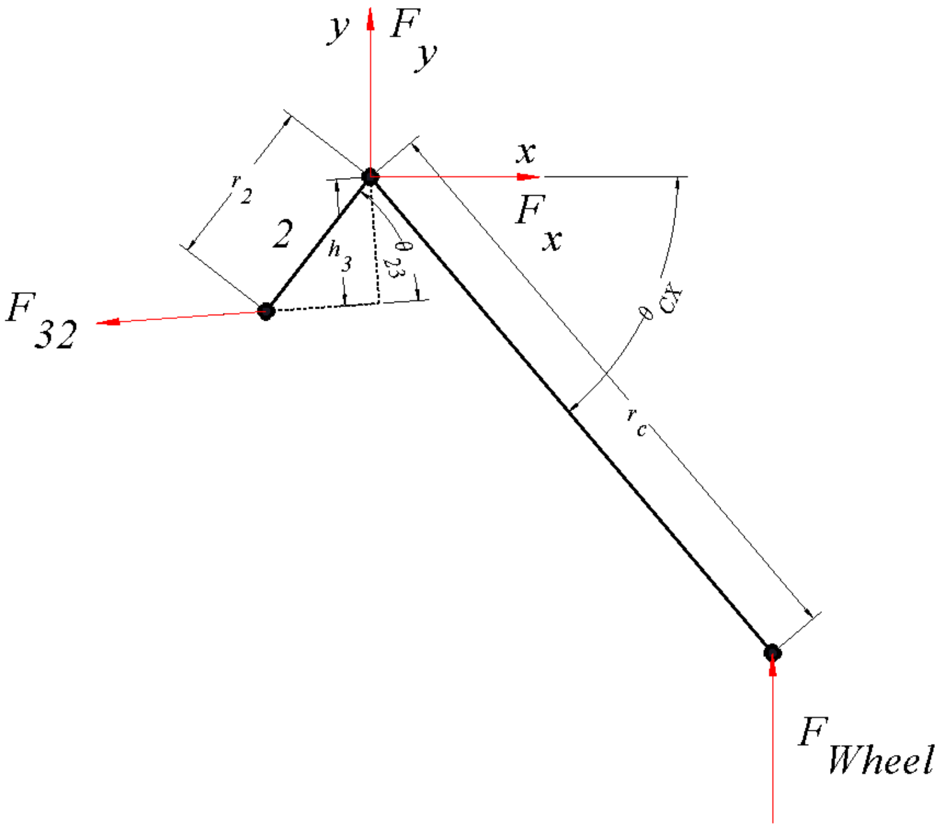


Figure 3.6 Free body diagram of link 2

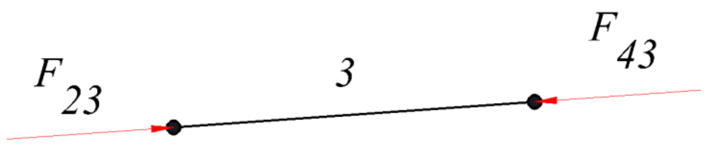


Figure 3.7 Free body diagram of link 3

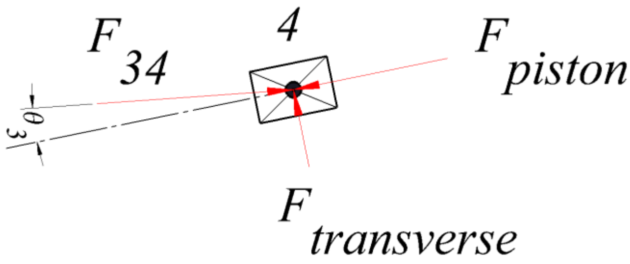


Figure 3.8 Free body diagram of link 4

It can be written from Figure 3.6;

$$F_{32} = \frac{F_{Wheel} \cdot r_c \cdot \cos(\theta_{CX})}{h_3} \tag{3.23}$$

and,

$$h_3 = r_2 \cdot \sin(\theta_{23}) \tag{3.24}$$

Also, it can be seen from Figure 3.3;

$$\theta_{23} = \theta_2 + \theta_3 - \pi \tag{3.25}$$

By rearranging the equations (3.23), (3.24), (3.25) the force acting on the piston rod can be written as a function of the wheel position.

$$F_{32} = \frac{F_{Wheel} \cdot r_c \cdot \cos(\theta_{CX})}{r_2 \cdot \sin(\theta_2 + \theta_3 - \pi)}$$

Also it can be seen that, the magnitudes of the forces F_{32} and F_{34} are equal to each other. Thus, by using the Figure 3.8, the longitudinal force (piston force) and the transverse force (guide ring force) acting on the piston can be written as follows;

$$F_{piston} = F_{34} \cdot \cos(\theta_3) = \frac{F_{Wheel} \cdot r_c \cdot \cos(\theta_{CX})}{r_2 \cdot \sin(\theta_2 + \theta_3 - \pi)} \cdot \cos(\theta_3) \tag{3.26}$$

$$F_{guidering} = F_{34} \cdot \sin(\theta_3) = \frac{F_{Wheel} \cdot r_c \cdot cos(\theta_{CX})}{r_2 \cdot sin(\theta_2 + \theta_3 - \pi)} \cdot \sin(\theta_3) \tag{3.27}$$

By using the equation (3.26), the spring force acting on the wheel can be written as;

$$F_{Wspring} = \frac{F_{Pspring} \cdot r_2 \cdot sin(\theta_2 + \theta_3 - \pi)}{r_c \cdot \cos(\theta_{CX}) \cdot \cos(\theta_3)} \tag{3.28}$$

Also viscous damping force acting to the wheel can be written as;

$$F_{Wdamping} = \frac{F_{Pdamping} \cdot r_2 \cdot sin(\theta_2 + \theta_3 - \pi)}{r_c \cdot \cos(\theta_{CX}) \cdot \cos(\theta_3)} \tag{3.29}$$

Substituting the equation (3.8) into equations (3.28) and (3.29), equations yields;

$$F_{Wspring} = \frac{F_{Pspring} \cdot r_2 \cdot sin(\theta_2 + \theta_3 - \pi)}{r_c \cdot \cos\left(asin\left(\frac{h}{r_c}\right)\right) \cdot \cos(\theta_3)}$$

$$F_{Wdamping} = \frac{F_{Pdamping} \cdot r_2 \cdot sin(\theta_2 + \theta_3 - \pi)}{r_c \cdot \cos\left(asin\left(\frac{h}{r_c}\right)\right) \cdot \cos(\theta_3)}$$

Finally the total force acting on the wheel can be written as follows.

$$F_{Wheel} = \frac{F_{Pspring} \cdot r_2 \cdot sin(\theta_2 + \theta_3 - \pi)}{r_c \cdot \cos\left(asin\left(\frac{h}{r_c}\right)\right) \cdot \cos(\theta_3)} + \frac{F_{Pdamping} \cdot r_2 \cdot sin(\theta_2 + \theta_3 - \pi)}{r_c \cdot \cos\left(asin\left(\frac{h}{r_c}\right)\right) \cdot \cos(\theta_3)} \tag{3.30}$$

Simplifying the equation (3.30) yields,

$$F_{Wheel} = \frac{\left(F_{Pspring} + F_{Pdamping}\right) \cdot r_2 \cdot sin(\theta_2 + \theta_3 - \pi)}{r_c \cdot \cos\left(asin\left(\frac{h}{r_c}\right)\right) \cdot \cos(\theta_3)}$$

4. DEVELOPMENT OF THE GRAPHICAL USER INTERFACE

A graphical user interface has been developed in the environment of "MATLAB-App Designer" by using the parametric equations which are derived in "PARAMETRIC MODELLING OF THE SYSTEM" topic.

Using the developed graphical user interface, determination and optimization of the parameters for designing a hydro-pneumatic suspension unit could be performed quickly and easily by iterating the input parameters. Thus, the time consumed in predesign phase could be reduced significantly.

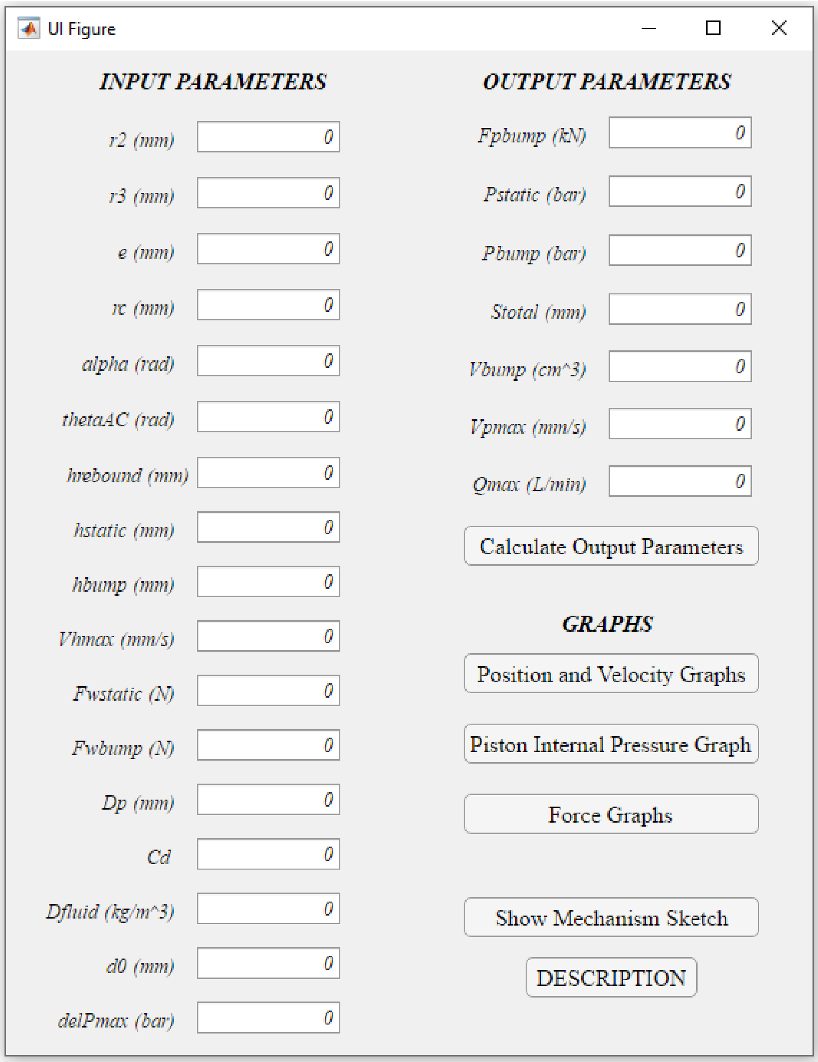


Figure 4.1 Main page of the developed GUI

The main page of the developed GUI has been shown in Figure 4.1. Output parameters, position and velocity graphs for hydraulic piston could be produced by filling the input parameters in the GUI. Moreover, gas pressure inside the gas chamber, spring reaction forces, damping reaction forces, total reaction forces on the wheel, force acting on the piston rod and force acting on the piston guide ring could also be plotted by using related buttons on the screen.

The explanations for input and output parameters have been shown in Table 4.1.

Table 4.1 Explanation of the parameters of the GUI

Parameter	Explanation of the Parameter
r2 (mm)	Length of link 2 (suspension arm) in Figure 3.3 Sketch of the mechanism
r3 (mm)	Length of link 3 (piston rod) in Figure 3.3 Sketch of the mechanism
e (mm)	Offset distance of the hydraulic cylinder from X axis
rc (mm)	Length of the wheel arm
alpha (rad)	Angle between x and X axis
thetaAC (rad)	Angle between suspension arm and wheel arm
hrebound (mm)	Distance between x axis and wheel axis when the system is at rebound position
hstatic (mm)	Distance between x axis and wheel axis when the system is at static position
hbump (mm)	Distance between x axis and wheel axis when the system is at bump position
Vhmax (mm/s)	Maximum vertical velocity of the wheel axis
Fwstatic (N)	Wheel load at static position
Fwbump (N)	Wheel load at bump position which is also equal to the maximum wheel load
Dp (mm)	Diameter of hydraulic and hydro-gas piston
Cd	Discharge coefficient at the orifice
Dfluid (kg/m^3)	Density of the used hydraulic oil
d0 (mm)	Diameter of the orifice
delPmax (bar)	Set pressure of the pressure relief valve
Fpbump (kN)	Piston reaction force when the system is at bump position which is also equal to maximum piston reaction force. This parameter might be used for calculating the maximum forces

	acting on the system components.
Pstatic (bar)	Pressure inside the cylinders when the system is at static position. This parameter is used for setting the initial pressure inside the gas chamber.
Pbump (bar)	Pressure inside the pistons when the system is at bump position which is also equal to the maximum pressure inside the pistons. This parameter might be used for determination of the wall thickness of the hydraulic and hydro-gas cylinders.
Stotal (mm)	Total piston stroke of the HSU
Vbump (cm^3)	Dead volume of the gas chamber
Vpmax (mm/s)	Maximum velocity of the pistons
Qmax (L/min)	Maximum flow rate of the hydraulic fluid

Six buttons have been placed on the main window of the GUI as seen in Figure 4.1. The functions of these buttons have been explained in Table 4.2. Templates of the 2D and 3D plots have been shown in Figure 4.2 and Figure 4.3 respectively.

Table 4.2 Functions of the buttons

Button Name	**Functions of the Buttons**
Calculate Output Parameters	Represents the output parameters on output parameters section
Position and Velocity Graphs	Plots the graphs of hydraulic piston position and velocity as a function of the wheel position and the wheel vertical velocity
Piston Internal Pressure Graph	Plots the graph of gas pressure inside the gas chamber as a function of wheel position
Force Graphs	Plots the graph of; spring reaction force, damper reaction force, total reaction force, force acting on the piston rod and force acting on the piston guide ring as a function of wheel position and vertical wheel velocity
Show Mechanism Sketch	Displays the sketch view of mechanism which contains the input parameters of the mechanism (Figure 4.4)
Description	Displays the description for input and output parameters to help the user (Figure 4.5)

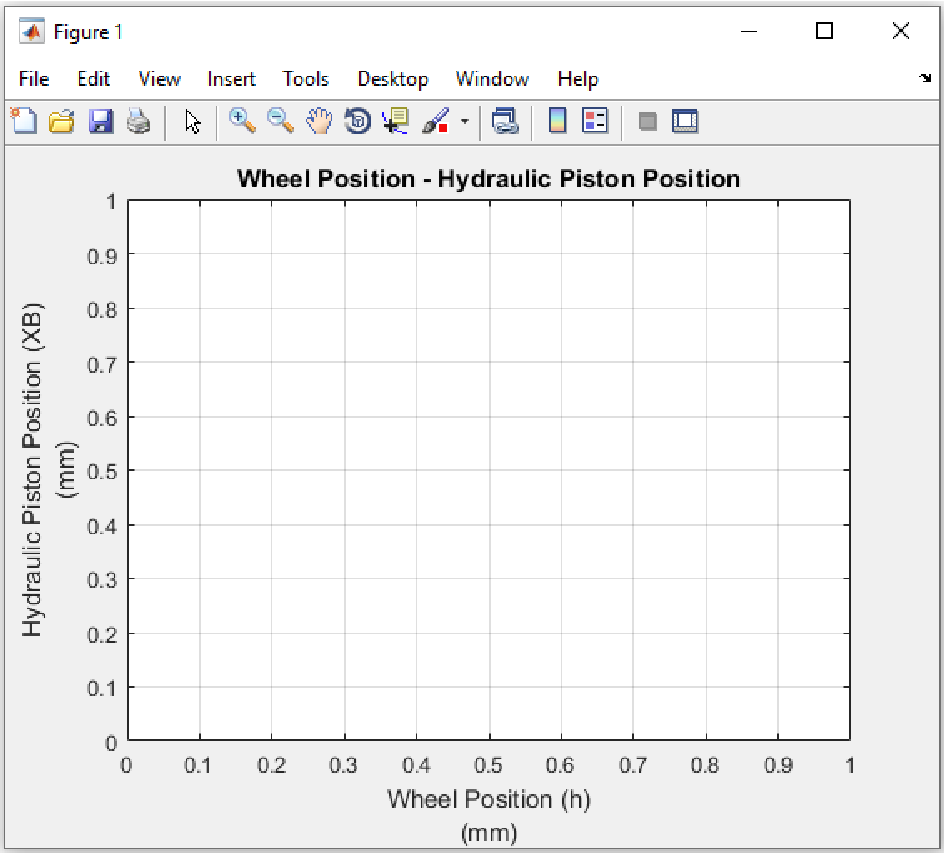


Figure 4.2 Template of a 2D graph

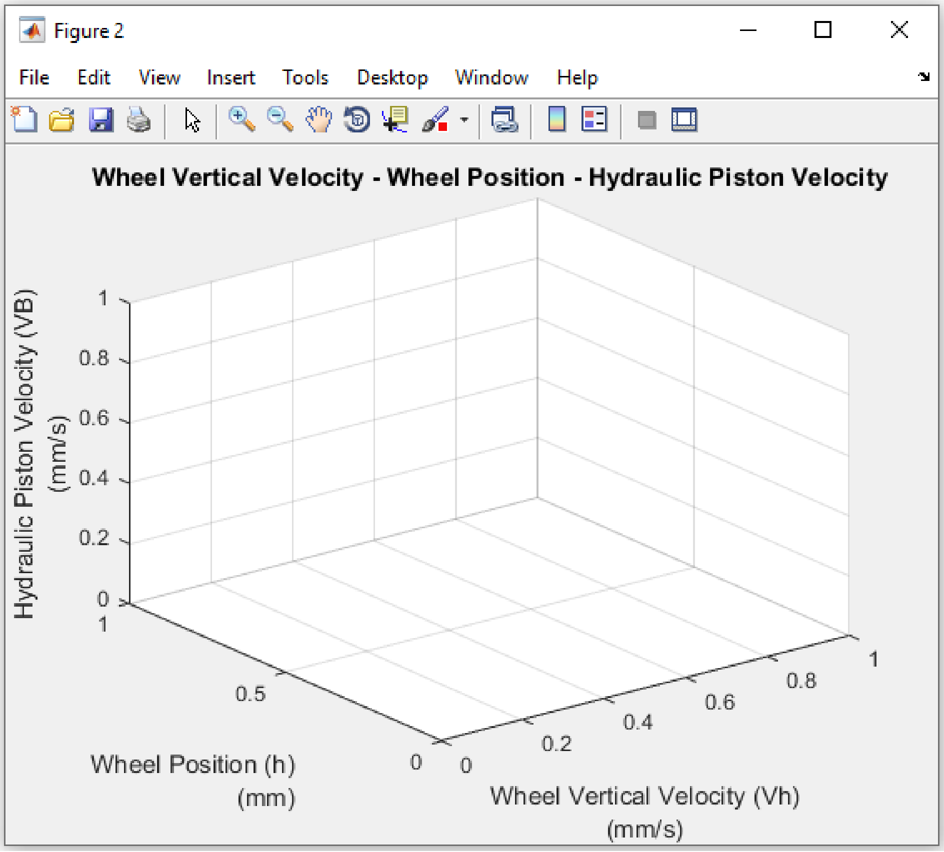


Figure 4.3 Template of a 3D graph

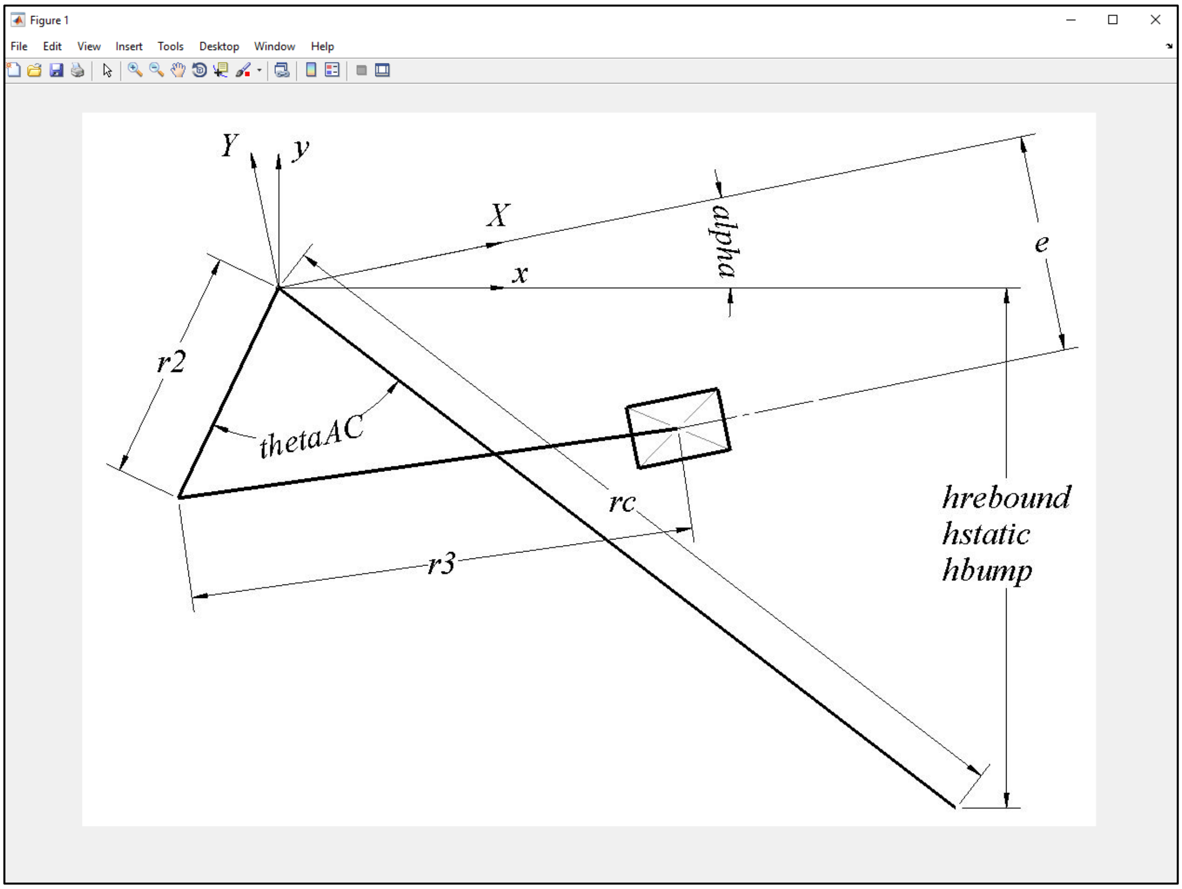


Figure 4.4 Mechanism sketch view

r2 (mm)	*: Crank radius*
r3 (mm)	*: Piston rod length*
e (mm)	*: Piston offset*
rc (mm)	*: Axle arm length*
alpha (rad)	*: Slope of piston axis*
thetaAC (rad)	*: Angle between crank radius and axle arm*
hrebound (mm)	*: Height of the wheel axis at rebound position*
hstatic (mm)	*: Height of the wheel axis at static position*
hbump (mm)	*: Height of the wheel axis at bump position*
Vhmax (mm/s)	*: Maximum vertical velocity of wheel axis*
Fwstatic (N)	*: Static wheel load*
Fwbump (N)	*: Maximum wheel load*
Dp (mm)	*: Piston diameter*
Cd	*: Discharge coefficient at orifice*
Dfluid (kg/m^3)	*: Density of hydraulic oil*
d0 (mm)	*: Orifice diameter*
delPmax (bar)	*: Pressure relief valve set pressure*
Fpbump (kN)	*: Maximum piston reaction force*
Pstatic (bar)	*: Piston (gas) pressure at static position*
Pbump (bar)	*: Maximum piston (gas) pressure*
Stotal (mm)	*: Total piston stroke*
Vbump (cm^3)	*: Required dead volume of hydro-gas piston*
Vpmax (mm/s)	*: Maximum velocity of the piston*
Qmax (L/min)	*: Maximum flow rate of the hydraulic fluid*

Figure 4.5 Description for input and output parameters

5. DESIGN AND ANALYSIS OF THE SYSTEM

It is known that designing a HSU is complicated and iterative process. The developed GUI has been used to adjust required input parameters for optimum HSU. By the help of the developed GUI, the iteration of the input and output parameters has been performed easily and quickly.

5.1. Input and Output Parameters (Numeric)

Firstly, the maximum vertical velocity of the wheel, static and dynamic load capacities of the HSU have been determined by considering the using field of the HSU. It has been assumed that, the designed HSU will be used in a tracked vehicle which has the weight of 24 tones and totally 12 HSU have been placed on the vehicle. For that reason, the static wheel load has been taken 2 tones (19.61 kN) and the dynamic wheel load has been taken 8 tones (78.45 kN). In reference [3], the experimental and theoretical studies have been performed for the frequencies of 0.1 Hz and 0.8 Hz. Moreover, in reference [6] the maximum vertical velocity of the wheel has been taken about 300 mm/s. In this study, it has been aimed that the designed HSU capable of working higher frequencies and velocities compared to the references [3] and [6]. Thus, the maximum vertical velocity of the wheel axis has been assumed 600 mm/s. The mechanism linkage has been created by taking into consideration of the volumetric restrictions. At last, by using the developed GUI, iteration has been performed and all the input parameters have been determined. The numerical values of input parameters for the designed HSU have been listed in Table 5.1.

Table 5.1 Numerical values of the input parameters

Parameter	Parameter Value	Description
r2 (mm)	150 mm	Determined from the mechanism linkage
r3 (mm)	325 mm	Determined from the mechanism linkage
e (mm)	140 mm	Determined from the mechanism linkage
rc (mm)	550 mm	Determined from the mechanism linkage
alpha (rad)	0.201 rad	Determined from the mechanism linkage
thetaAC (rad)	1.361 rad	Determined from the mechanism linkage

hrebound (mm)	470 mm	Determined from the mechanism linkage
hstatic (mm)	335 mm	Determined from the mechanism linkage
hbump (mm)	100 mm	Determined from the mechanism linkage
Vhmax (mm/s)	600 mm/s	Determined from the system limit
Fwstatic (N)	19.61 kN (2 tones)	Determined from the system limit
Fwbump (N)	78.45 kN (8 tones)	Determined from the system limit
Dp (mm)	100 mm	Determined by iteration
Cd	0.9	Orifice discharge coefficient
Dfluid (kg/m^3)	860 kg/m^3	Fluid density
d0 (mm)	3 mm	Determined by the iteration
delPmax (bar)	80 bar	Determined by the iteration

The output parameters have been achieved and related graphics have been plotted by using the developed GUI. The achieved output parameters for designed HSU have been listed in Table 5.2.

Table 5.2 Achieved output parameters for designed HSU

Parameter	**Explanation of Parameter**
Fpbump (kN)	288.4 kN
Pstatic (bar)	86.87 bar
Pbump (bar)	367.2 bar
Stotal (mm)	107.2 mm
Vbump (cm^3)	283 cm^3
Vpmax (mm/s)	172.5 mm/s
Qmax (L/min)	81.28 L/min

Input and calculated output parameters of the system have been shown in Figure 5.1. Also, the plots obtained by using the input parameters have been shown in Figure 5.2, Figure 5.3, Figure 5.4, Figure 5.5, Figure 5.6, Figure 5.7, Figure 5.8 and Figure 5.9.

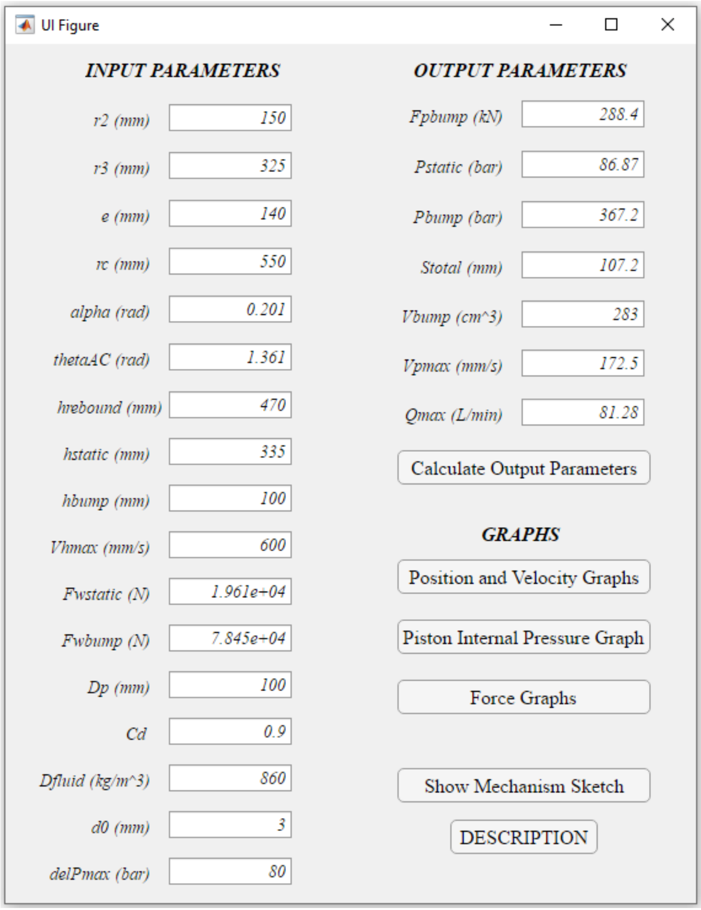


Figure 5.1 Display of the input and calculated output parameters

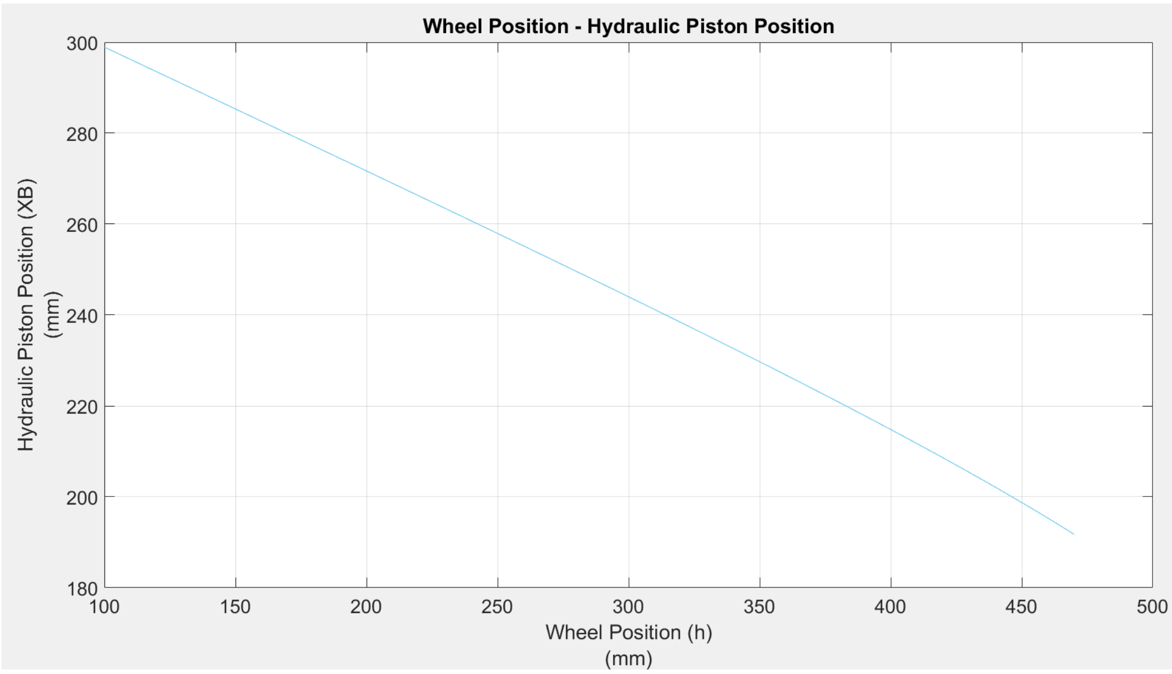


Figure 5.2 Wheel position – Hydraulic piston position plot

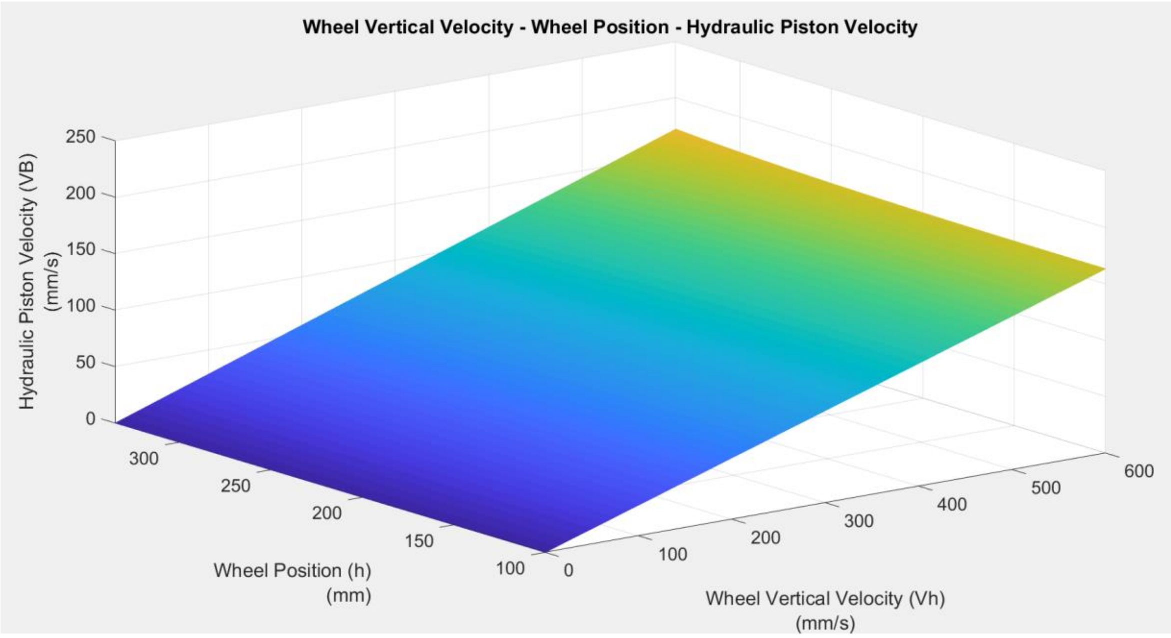


Figure 5.3 Wheel vertical velocity – Wheel position – Hydraulic piston velocity plot

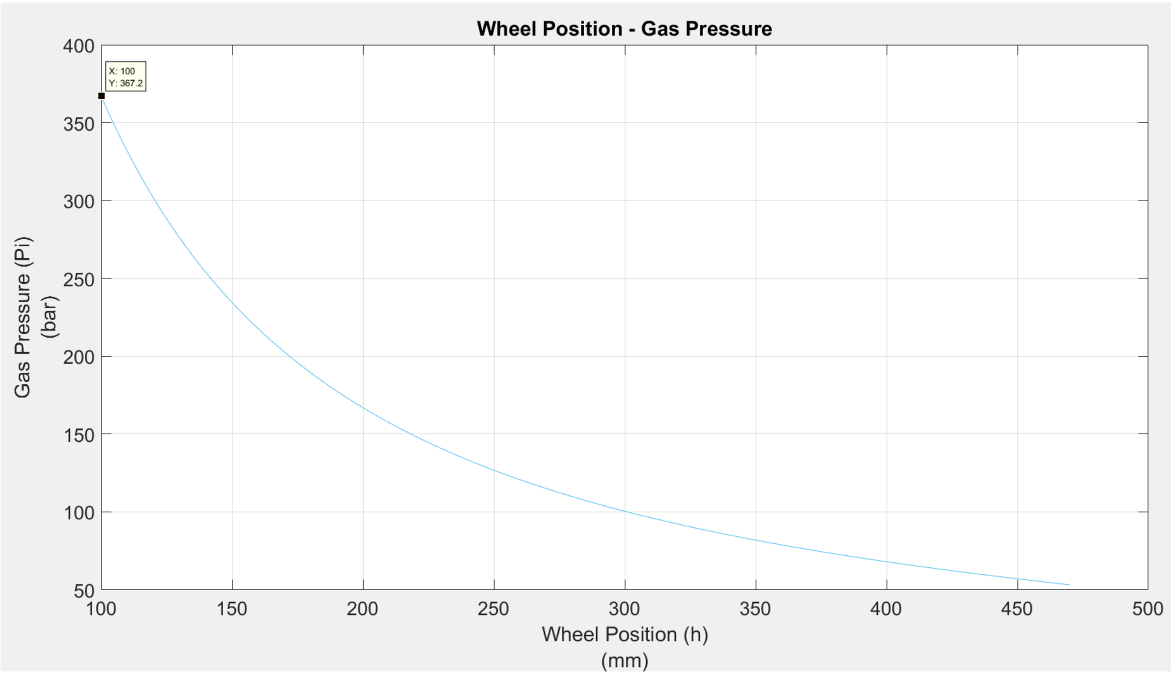


Figure 5.4 Wheel position – Gas pressure plot

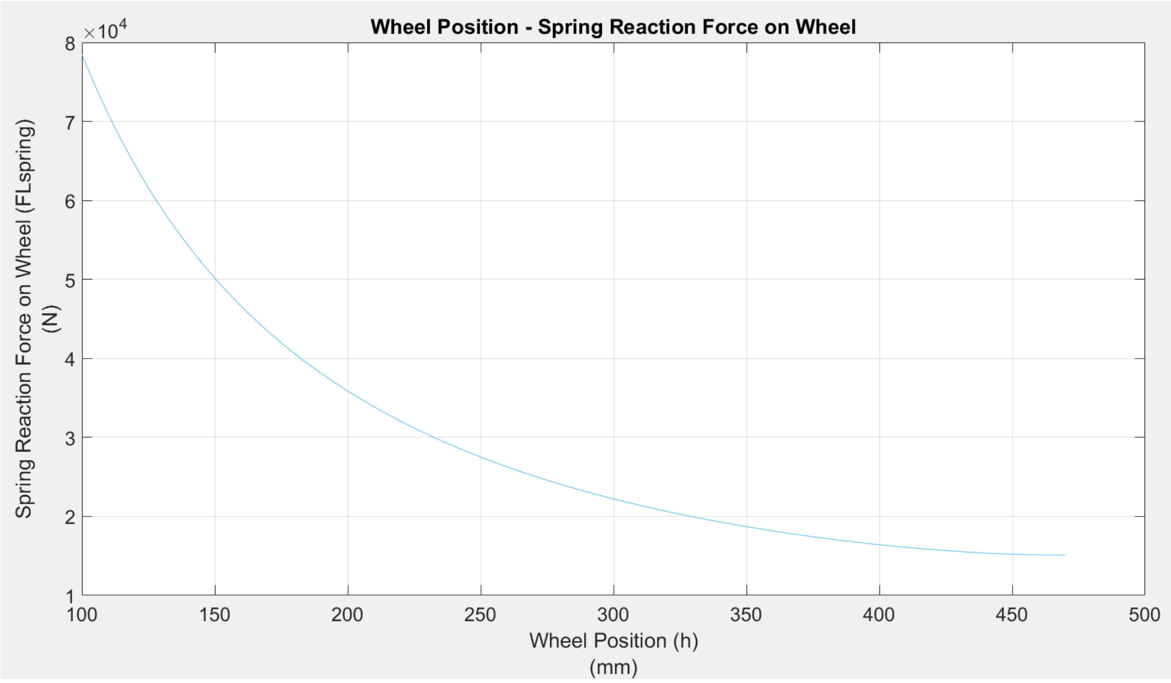


Figure 5.5 Wheel position – Spring reaction on the wheel plot

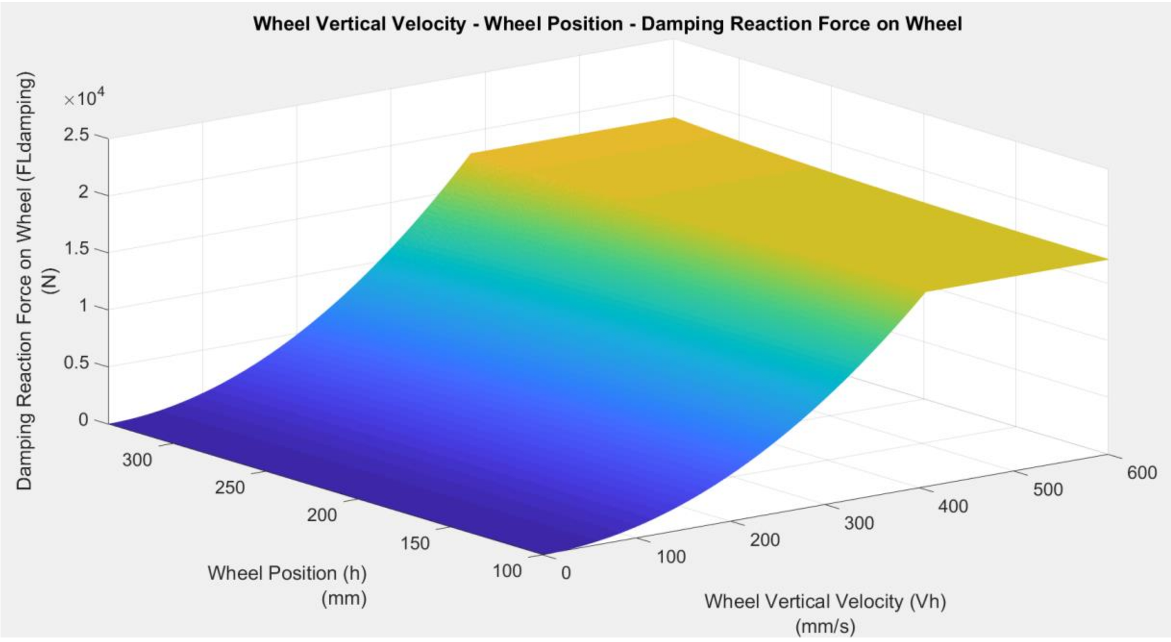


Figure 5.6 Wheel vertical velocity – Wheel position – Damping reaction force on the wheel plot

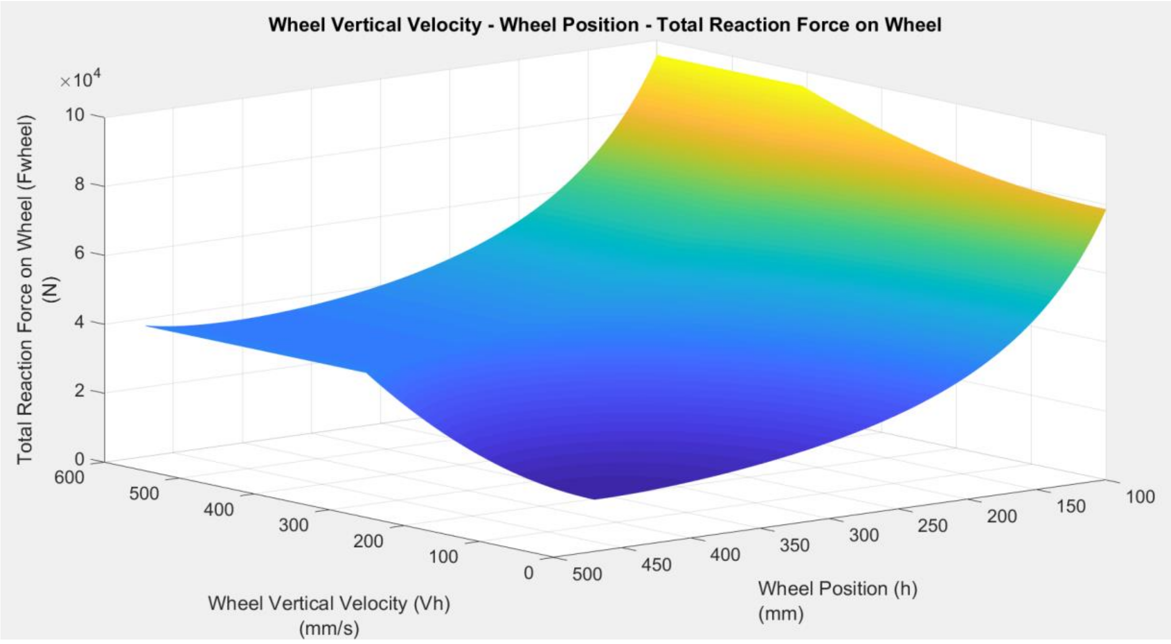


Figure 5.7 Wheel vertical velocity – Wheel position – Total reaction force on the wheel plot

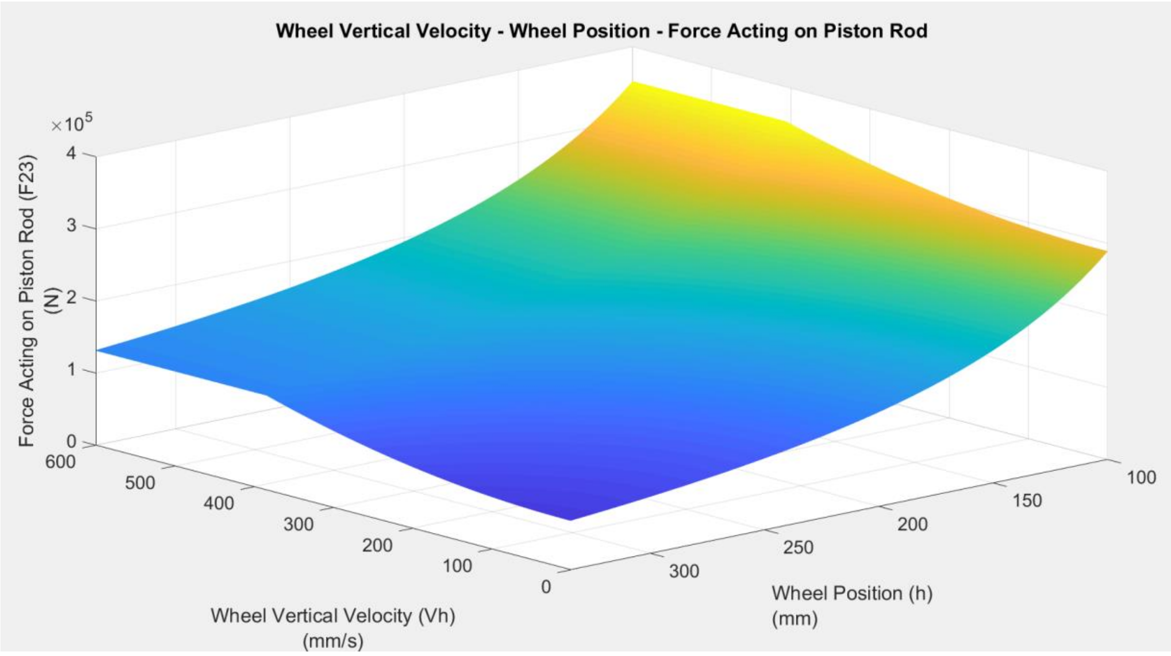


Figure 5.8 Wheel vertical velocity – Wheel position – Force acting on piston rod plot

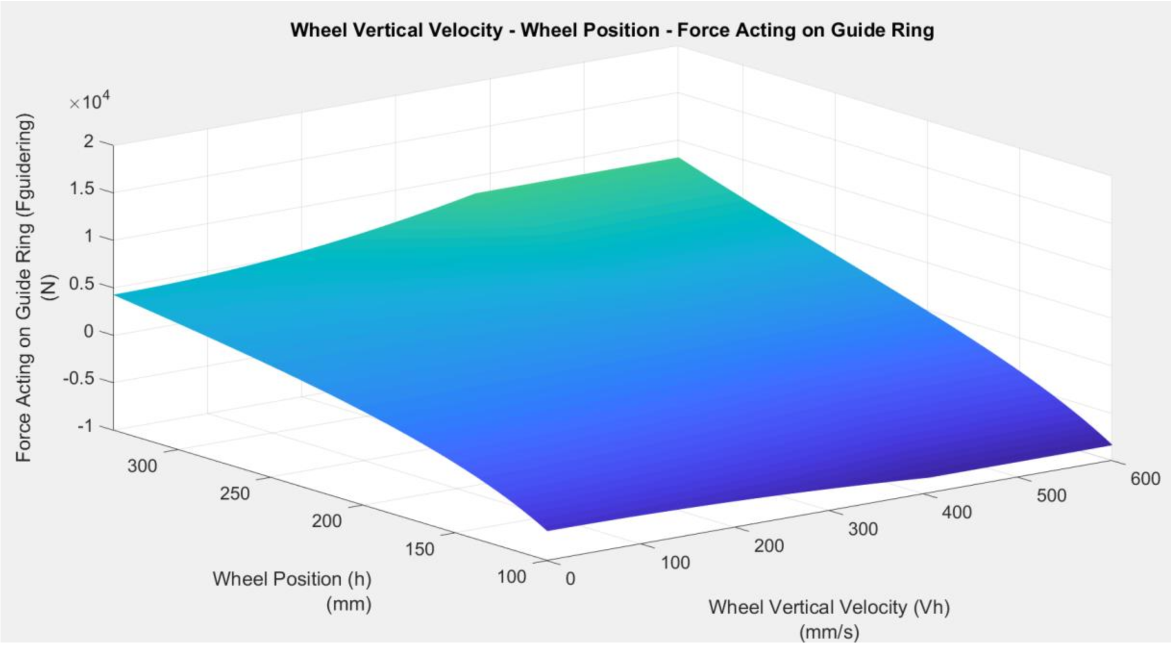


Figure 5.9 Wheel vertical velocity – Wheel position – Force acting on piston guide ring plot

5.2. Detailed 3D CAD Model Design and Drawings of the HSU

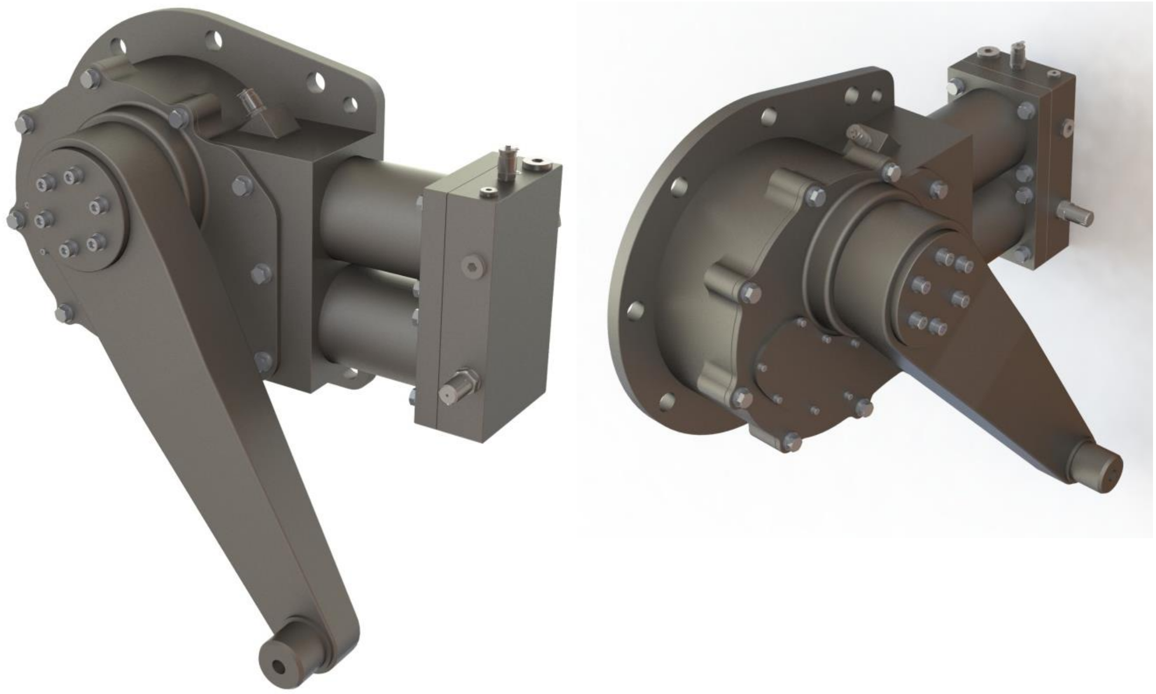


Figure 5.10 Isometric views of the designed HSU

In the detailed design process,

- The components of the HSU have been designed and modeled by taking into consideration the parameters which have been achieved by using the developed GUI.
- The commercial off the shelf (COTS) items have been determined.
- Using the designed parts and the COTS items, the subassemblies and the main assembly have been created.
- Bill of materials for the designed HSU, which contains all the parts and the COTS items, has been created.
- Drawings for the assemblies and the parts have been generated.

The isometric views of the designed hydro-pneumatic suspension unit have been shown in Figure 5.10.

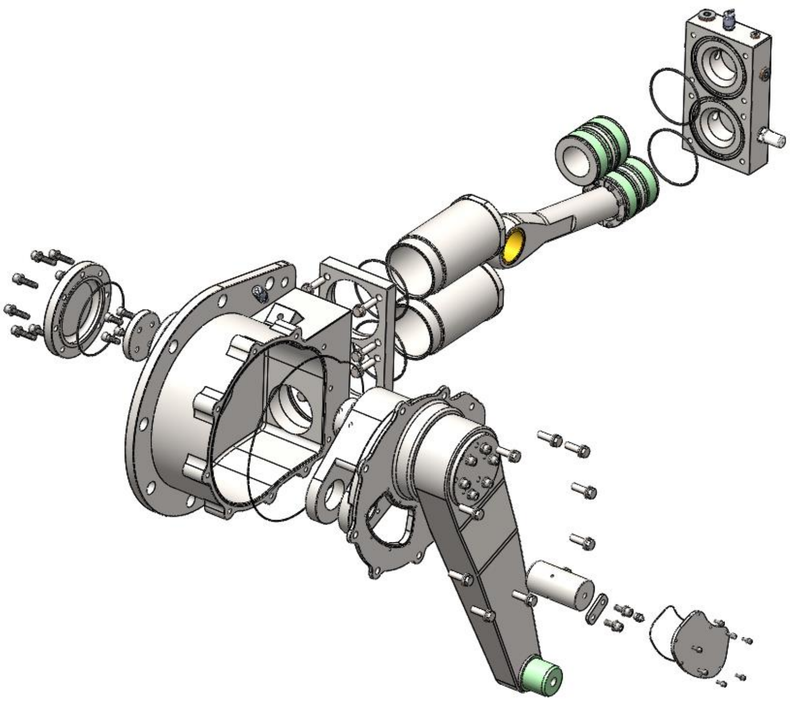


Figure 5.11 Exploded view of the HSU (Subassemblies have not been exploded)

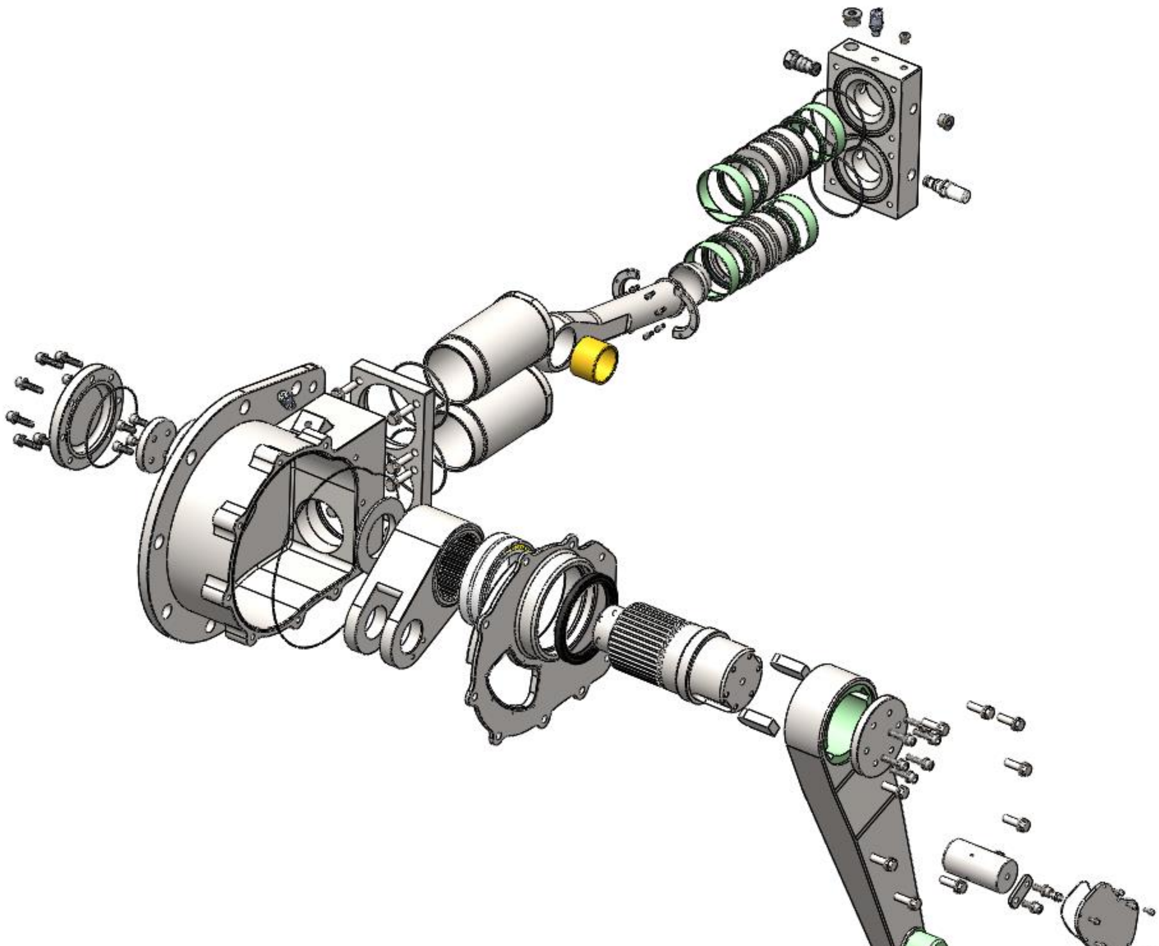


Figure 5.12 Fully exploded view of the HSU

The exploded views of the HSU have been shown in Figure 5.11 and Figure 5.12. The HSU is consisted of four subassemblies which are; suspension arm assembly (Figure 5.21), hydraulic piston assembly (Figure 5.28), hydro-gas piston assembly (Figure 5.30) and hydraulic block assembly (Figure 5.32). In this section; parts, subassemblies, sealing details of the design, bill of materials and drawings of the designed HSU have been described.

5.2.1. Parts and subassemblies of the HSU

- Stationary casing :

Stationary casing have been used for fixing the system to the vehicle body. Bolt and pin holes on the stationary casing have been utilized to mount the HSU to the vehicle body. Front cover, rear cap and piston cylinders have also been mounted on the stationary casing. Moreover, the nitrogen gas filling interface has been located on the stationary casing. The isometric views of the stationary casing have been shown in Figure 5.13.

The downward motion of the wheel arm has been limited with the extruded section inside the casing. The surface of the suspension arm pushes the surface of the extruded section inside the casing, while the suspension arm is at the end of the downward stroke as seen in Figure 5.14.

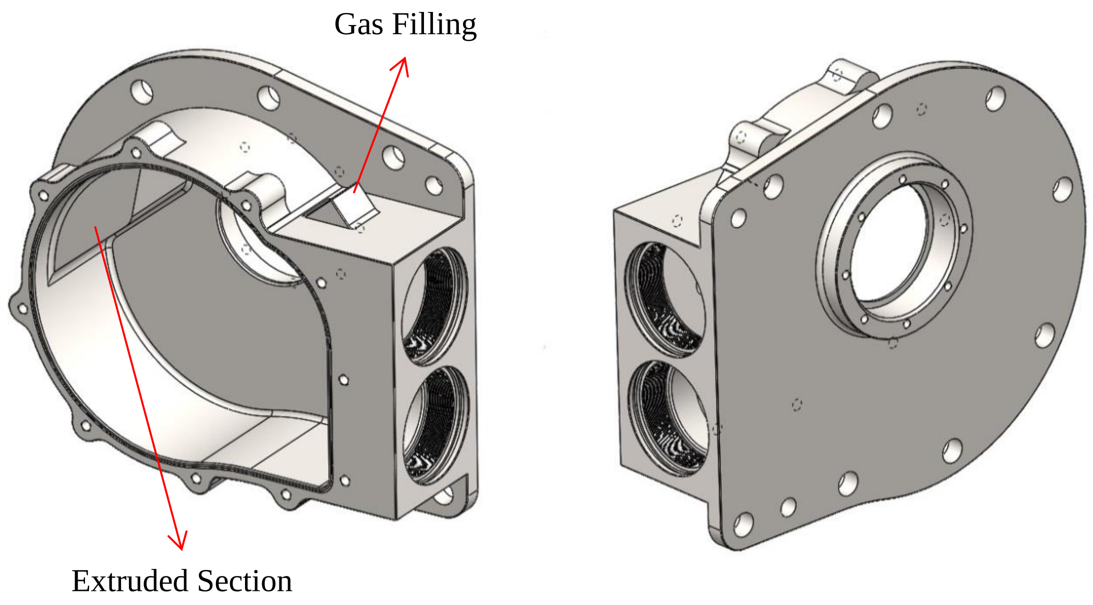


Figure 5.13 Isometric views of the stationary casing

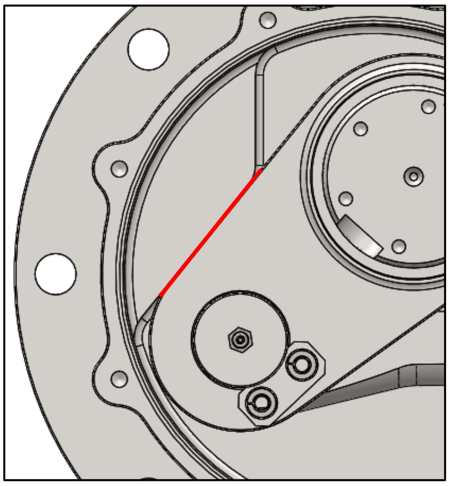


Figure 5.14 Position of the wheel arm at the end of the downward stroke

- Piston pin and anchorage plate :

Connection of the suspension arm and the piston rod has been provided with the piston pin. Lubrication holes have been drilled into pin for greasing the joint by using a grease nipple. Piston pin have been fixed on to the suspension arm by using the anchorage plate. Isometric view of the piston pin has been shown in Figure 5.15. Also, assembled view of the anchorage plate, grease nipple and piston pin have been shown in Figure 5.16.

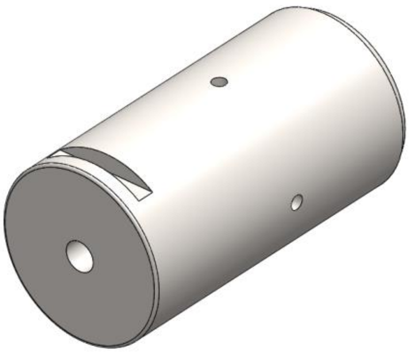


Figure 5.15 Isometric view of the piston pin

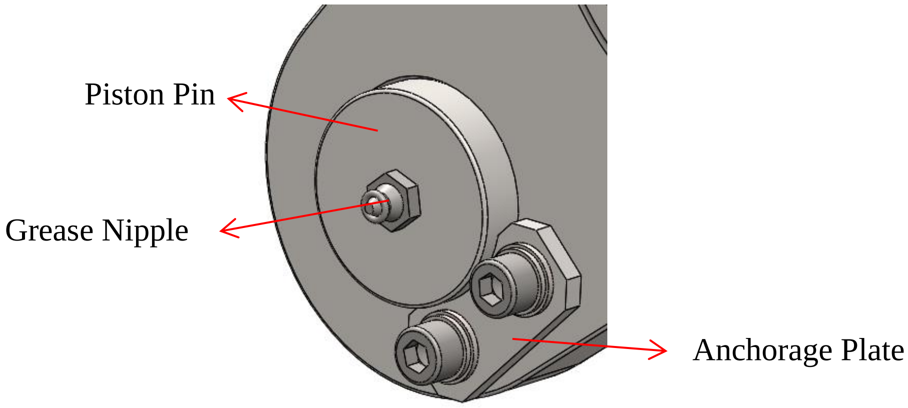


Figure 5.16 Assembled view of the anchorage plate, grease nipple and piston pin

- Piston cylinder :

There are two piston cylinders in designed HSU which have been assembled parallel to each other. Piston cylinders have been fixed on the stationary casing via the threaded portion. The tightening of piston cylinders have been performed from the wrench flats on the part. The isometric view of the piston cylinder has been shown in Figure 5.17.

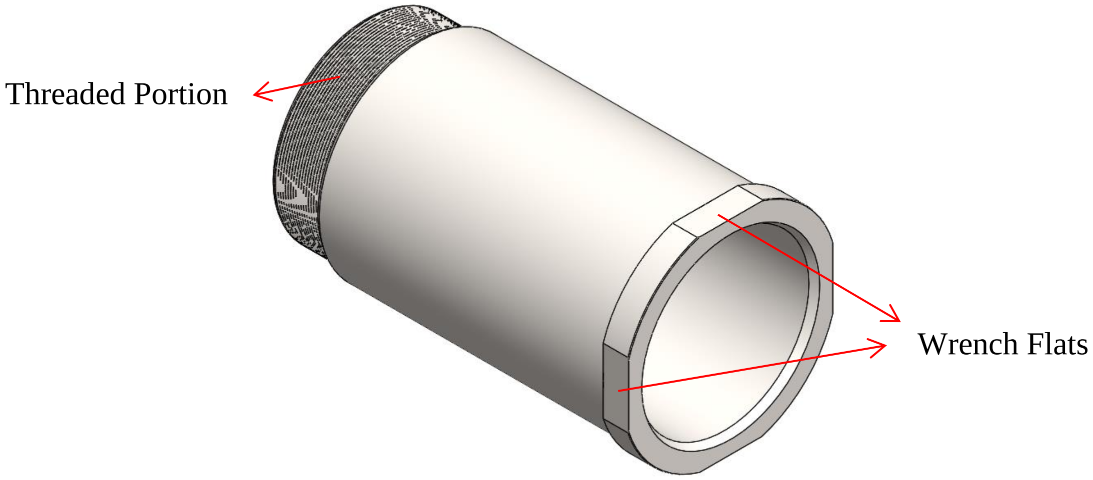


Figure 5.17 Isometric view of the piston cylinder

- Hydraulic block cap

The hydraulic block cap has been designed for fixing the hydraulic block to the piston cylinders. The isometric view of the hydraulic block cap has been shown in Figure 5.18.

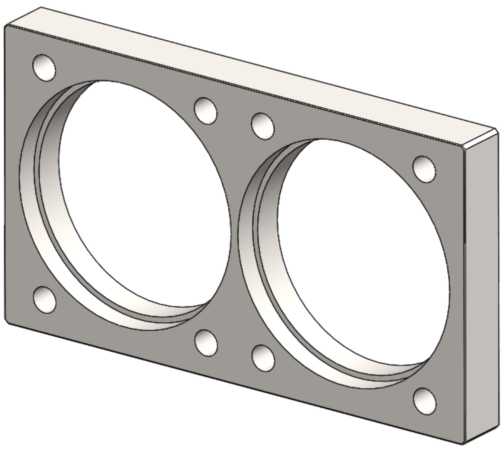


Figure 5.18 Isometric view of the hydraulic block cap

- Bearing cap and rear cap :

Bearing cap and rear cap have been designed for fixing the spherical roller bearing on arm shaft and stationary casing. The isometric views of the bearing cap and the rear cap have been shown in Figure 5.19.

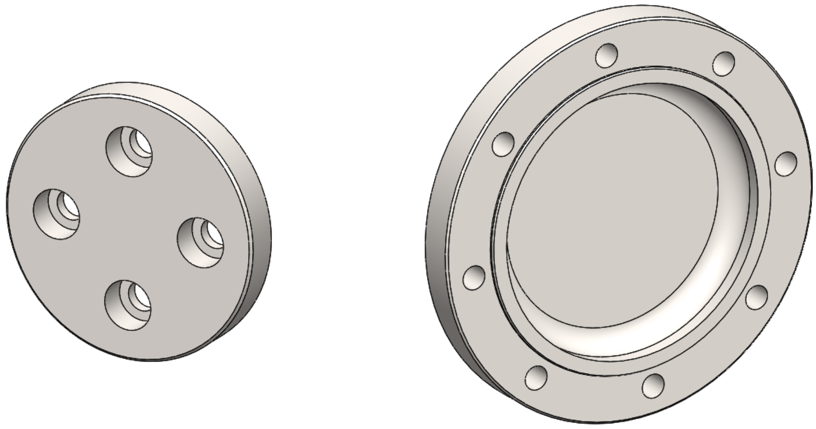


Figure 5.19 Isometric views of the bearing cap and rear cap

- Maintenance cap :

The maintenance cap has been designed for accessing the suspension arm - piston rod joint. By removing the maintenance cap, assembling and disassembling of the joint, also greasing of the joint can be performed easily. The isometric view of the maintenance cap has been shown in Figure 5.20.

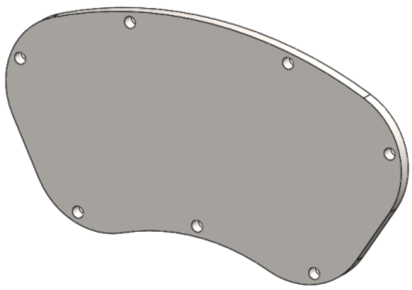


Figure 5.20 Isometric view of the maintenance cap

- Suspension arm assembly :

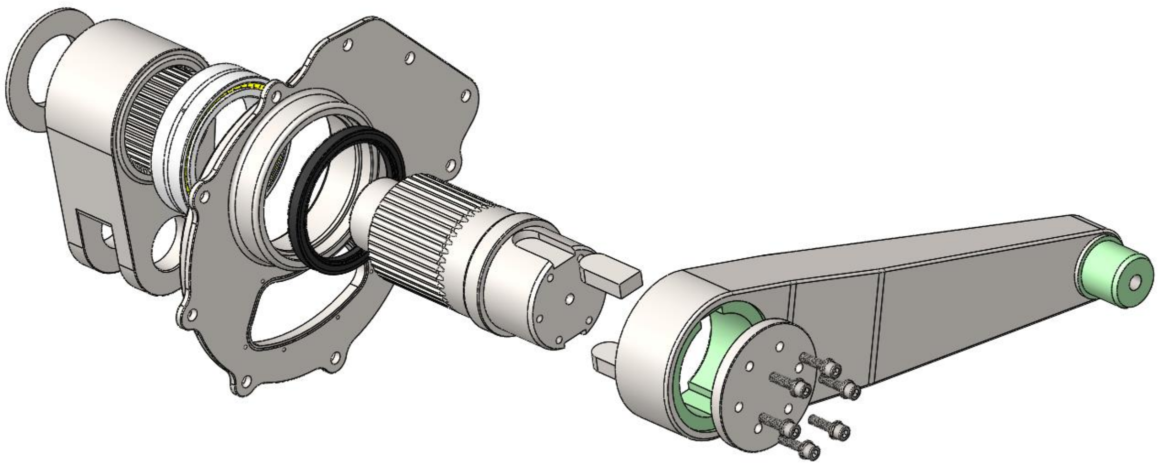


Figure 5.21 Exploded view of the suspension arm assembly

The exploded view of the suspension arm assembly has been shown in Figure 5.21 and the section view of the suspension arm assembly has been shown in Figure 5.26. The suspension arm assembly is consisted of front cover (Figure 5.22), locating shim (Figure 5.23), arm shaft (Figure 5.24), suspension arm (Figure 5.25), wheel arm (Figure 5.27), wheel arm cap (Figure 5.23), keys (Figure 5.23) and the COTS items (Cylindrical roller bearing, rotary seal, bolts, washers and spring washers).

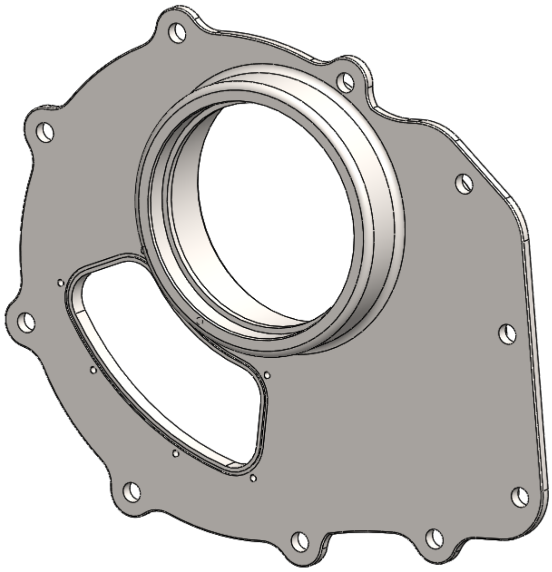


Figure 5.22 Isometric view of the front cover

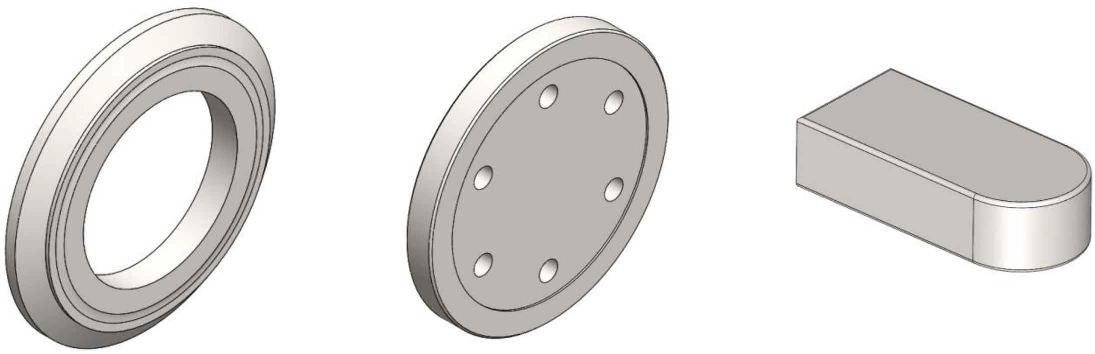


Figure 5.23 Isometric views of the locating shim, the wheel arm cap and the key

Wheel arm and suspension arm have been located on the arm shaft. The orientation of the wheel arm, the suspension arm and the arm shaft related to each other is directly effects the linkage positions of the mechanism in assembled state of the HSU. For that reason, position of the keyways on the wheel arm, the position of the keyways according to the spline profile on the arm shaft and the orientation of the spline profile according to the cartesian axis of the suspension arm are quite important.

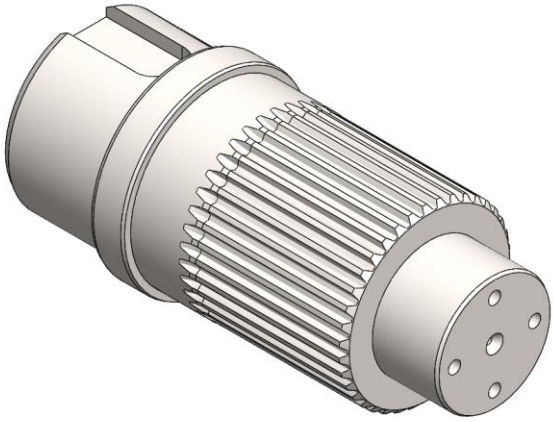


Figure 5.24 Isometric view of the arm shaft

The wheel arm has been interference fitted on the arm shaft and transmits the torque produced, due to the force on the wheel arm hub. The torque has been transmitted from wheel arm to arm shaft with keys and the friction force occurred between the interference fitted surfaces of the parts. So, pulling out of the wheel arm and the keys from the suspension arm has been blocked with the wheel arm cap. Also the suspension arm has been fitted on the arm shaft by using the splined connections on the parts. The arm shaft has been located on the front cover by using a cylindrical roller bearing and a rotary seal has been used for isolating the interior of the system from environmental effects. The whole location of the suspension arm assembly into the stationary casing has been determined by the locating shim.

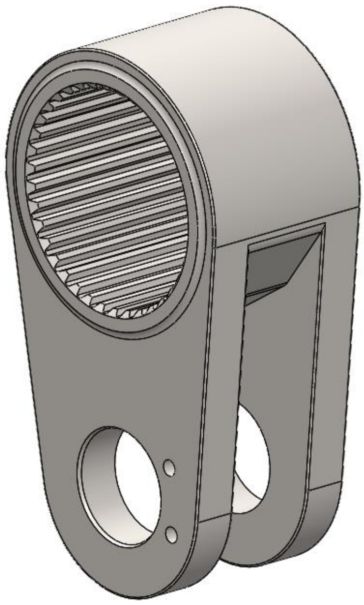


Figure 5.25 Isometric view of the suspension arm

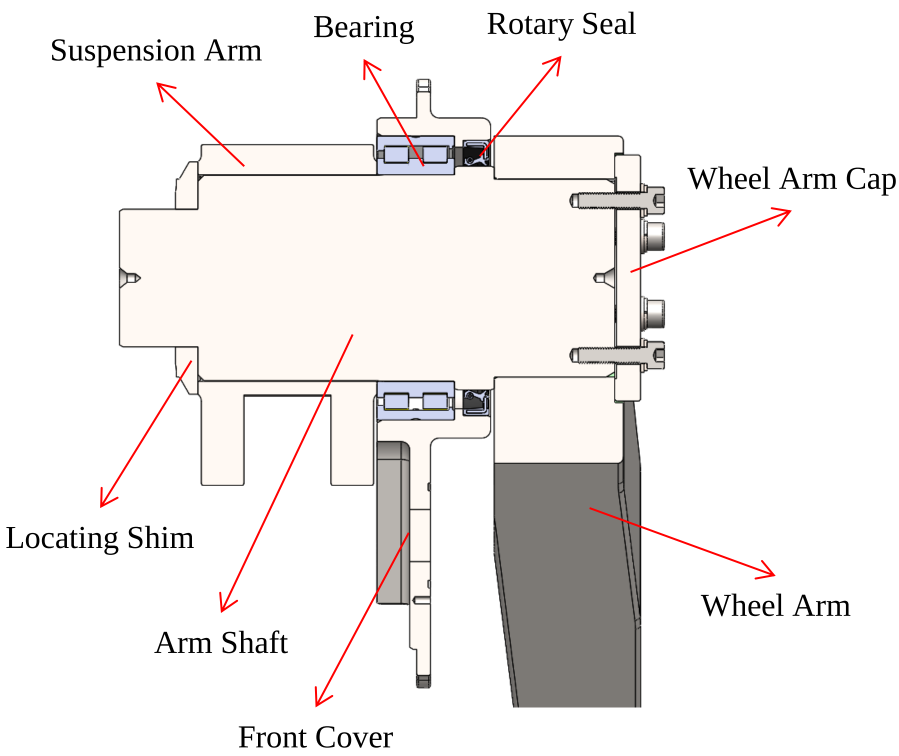


Figure 5.26 Section view of the suspension arm assembly

Wheel arm is consisted of two parts which welded and joined together. Firstly these parts have been roughly machined and welded. After that the welded parts have been machined to satisfy the close tolerances on the part. The green painted surfaces shown in Figure 5.27 have been machined after welding of the parts.

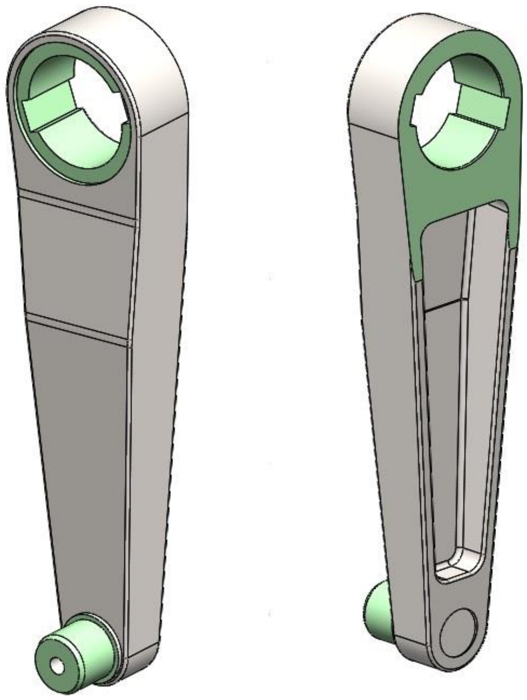


Figure 5.27 Isometric views of the wheel arm

- Hydraulic piston assembly :

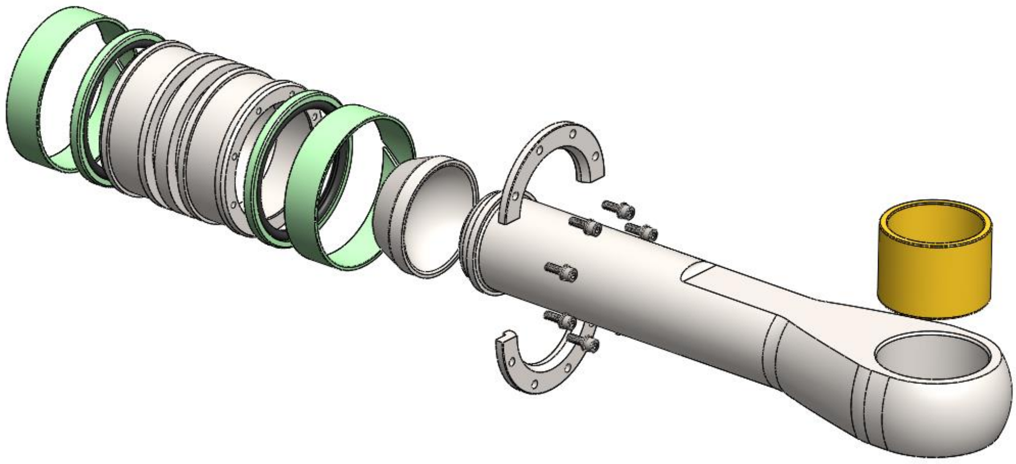


Figure 5.28 Exploded view of the hydraulic piston assembly

The exploded view of the hydraulic piston assembly has been shown in Figure 5.28 and the section view of the hydraulic piston assembly has been shown in Figure 5.29. The hydraulic piston assembly is consisted of hydraulic piston, piston rod bushing, piston front cap, piston friction bushing, hydraulic piston and the COTS items (Seals, piston guide rings, bolts, washers and spring washers).

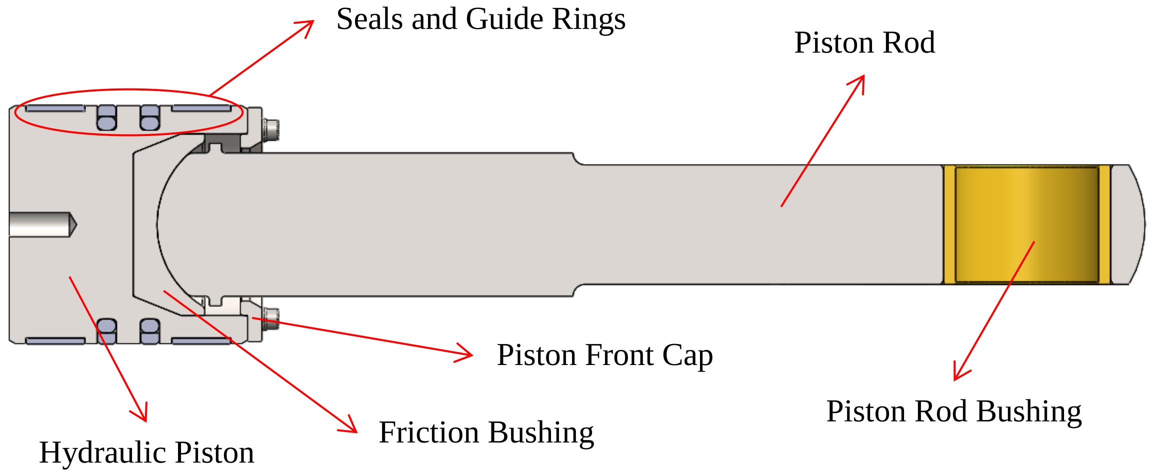


Figure 5.29 Section view of the hydraulic piston assembly

As known from slider crank mechanism, the movement of the piston rod is not linear. When the wheel arm moves, piston rod linearly displaces and rotates from the joint of the hydraulic piston. Likewise, the piston rod makes relative motion to the suspension arm. For that reasons, the friction bushing and the piston rod bushing have been designed to prevent the wear and reduce the friction at the joints. Piston guide rings have been used for absorbing the transverse forces occurred between piston and cylinder.

- Hydro-gas piston assembly

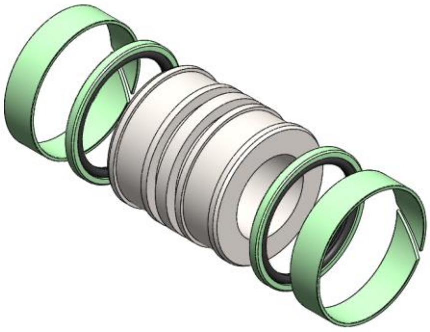


Figure 5.30 Exploded view of the hydro-gas piston assembly

The exploded view of the hydro-gas piston assembly has been shown in Figure 5.30 and the section view of the hydro-gas piston assembly has been shown in Figure 5.31. Hydro-gas piston assembly is consisted of hydro-gas piston, seals and piston guide rings. Note that, volume of the groove inside the hydro-gas piston is equal to the calculated dead volume of the hydro-gas piston.

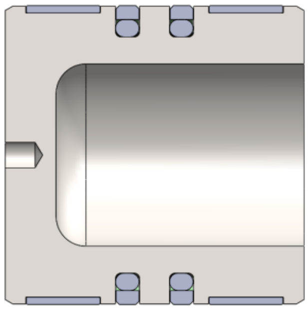


Figure 5.31 Section view of the hydro gas piston assembly

- Hydraulic block assembly

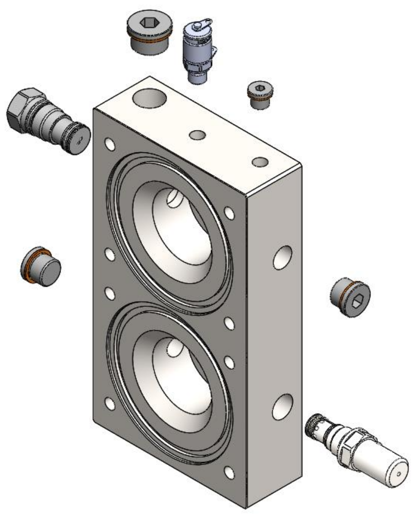


Figure 5.32 Exploded view of the hydraulic block assembly

The exploded view of the hydraulic block assembly has been shown in Figure 5.32. The hydraulic block assembly is consisted of the hydraulic block and the COTS items (pressure relief valve, orifice check valve, hydraulic connector and plugs). The pressure relief valve and orifice check valve have been selected by considering the maximum flow rate of the hydraulic oil, the maximum pressure inside the piston and the designed orifice diameter of the HSU.

5.2.2. Sealing details of the design

When the system was designing, it has been known that the designed system is going to be work at harsh environmental conditions. Therefore, the sealing of the system from environmental conditions plays critical role for increasing the life and the reliability of the system. Also, the sealing performance of the piston seals inside the system (hydraulic piston seals and hydro-gas piston seals) is another important subject for the life and the performance of the designed system.

The sealing between the stationary parts have been ensured by using O-rings. Suitable O-ring grooves have been machined to the related parts. The O-rings used in the HSU have been shown in Figure 5.33, Figure 5.34, Figure 5.35 and Figure 5.36.

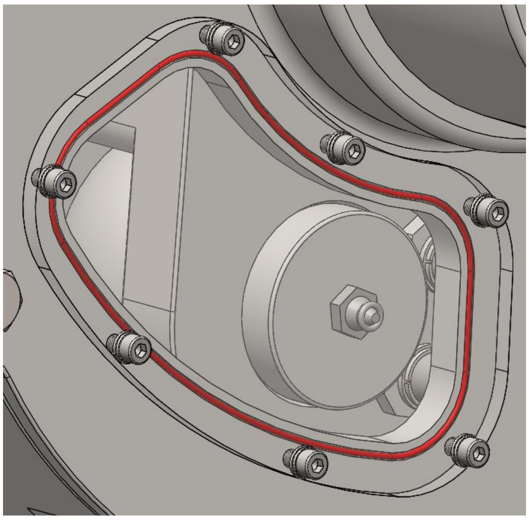


Figure 5.33 O-ring used under maintenance cap

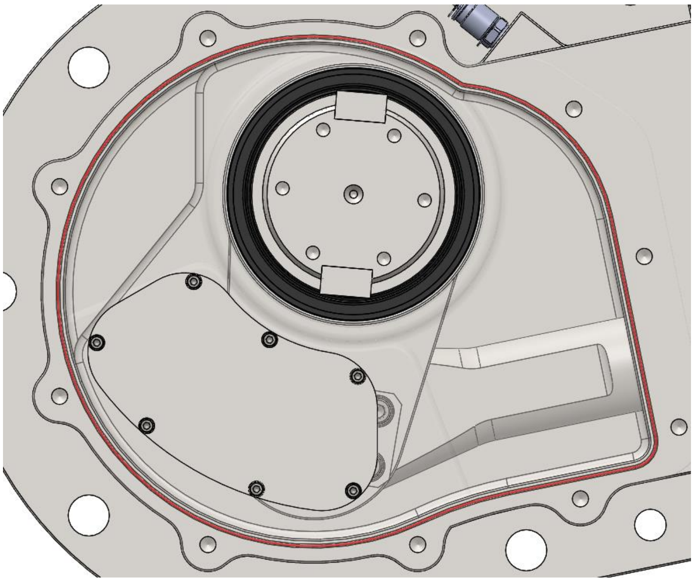


Figure 5.34 O-ring used under front cover

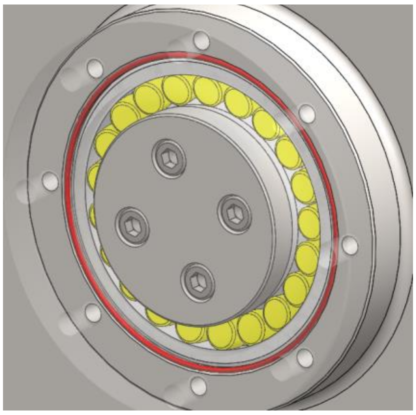


Figure 5.35 O-ring used under rear cap

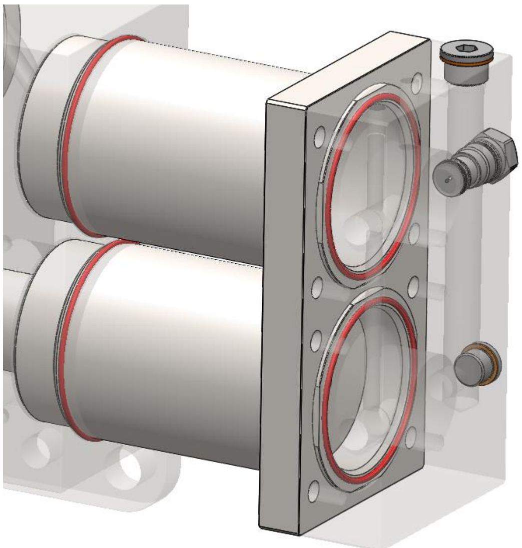


Figure 5.36 O-rings used in cylinders and hydraulic block assemblies

The sealing of the rotating parts have been ensured by using the rotary seal between the rotating and stationary parts. The only rotating part outside the HSU is arm shaft; the used rotary seal has been shown in Figure 5.37.

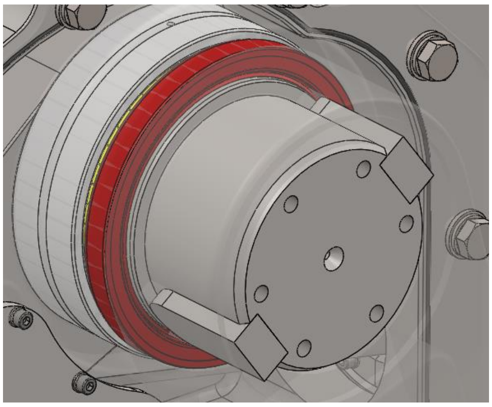


Figure 5.37 Rotary seal used in the HSU

As mentioned the sealing performance of the piston seals are critical for the system. Considering the maximum working velocity of the seals and maximum pressure inside the cylinders, proper seals have been selected. Also, the transverse forces acting on the seals have been diminished by using guide rings. The selected piston seals and guide rings have been shown in Figure 5.38.

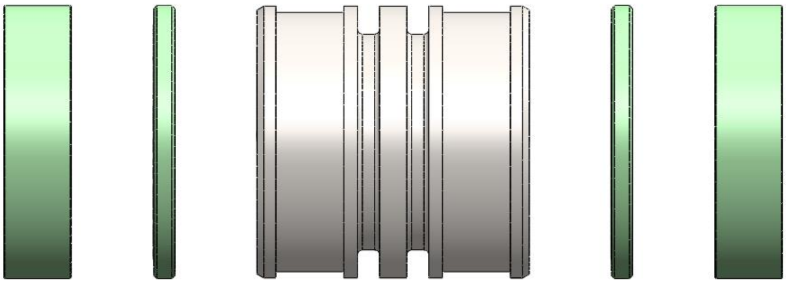


Figure 5.38 Piston seals and guide rings

The maximum pressure inside the cylinder and the maximum velocity of the seals has been determined from the values obtained by output parameters of the GUI as 367.2 bar and 172.5 mm/s respectively. The velocity of the hydraulic piston has been plotted as a function of wheel vertical velocity and wheel position as shown in Figure 5.39.

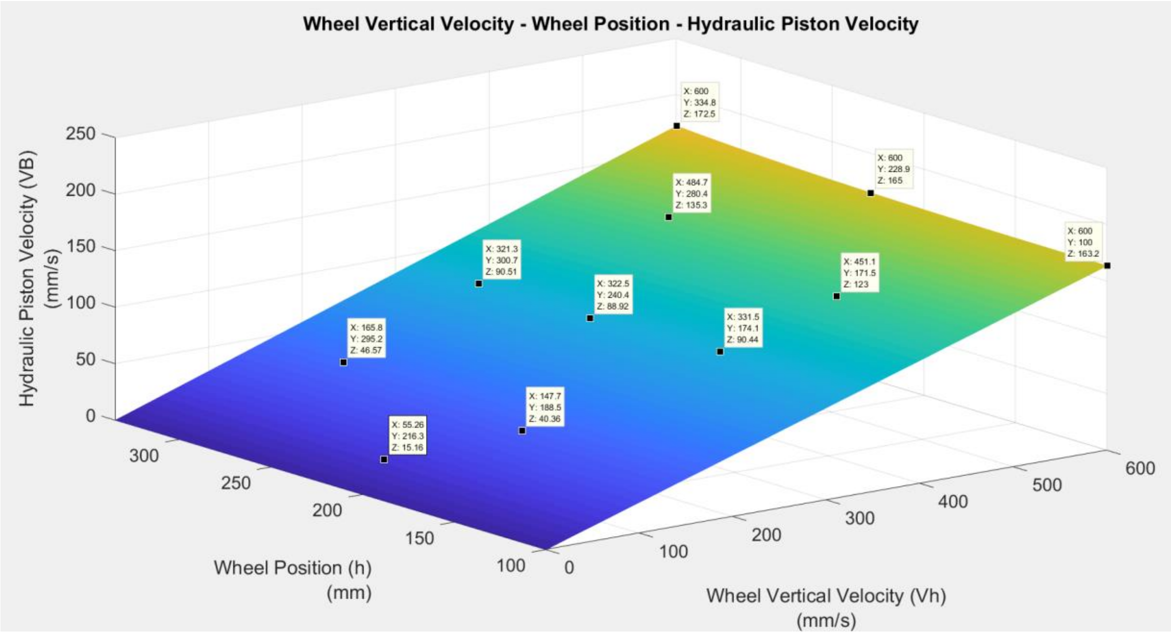


Figure 5.39 Hydraulic piston velocity plot

Surface pressures on the guide rings of the hydraulic piston have been calculated by using the maximum force acting on the guide ring ($F_{guidering}$= 8361 N), which have been taken from the "Wheel Vertical Velocity – Wheel Position – Force Acting on Guide Ring" plot as seen in Figure 5.40. Also it is known that, piston diameter (D_p) is 100mm and the total width of the used guide rings in hydraulic piston ($W_{guidering}$) is 50mm. Then the surface pressure on the guide ring has been calculated as follows;

$$P_{guidering} = \frac{F_{guidering}}{D_p \cdot W_{guidering}} = \frac{8361\ N}{(100\ mm) \cdot (50\ mm)} \cong 1.8\ MPa$$

For chosen guide rings the maximum allowable surface pressure is ($P_{all.guidering}$) 12 MPa. Then factor of safety ($F_{s.guidering}$) for the chosen guide rings have been calculated as;

$$F_{s.guidering} = \frac{P_{all.guidering}}{P_{guidering}} = \frac{12\ MPa}{1.8\ MPa} = 6.67$$

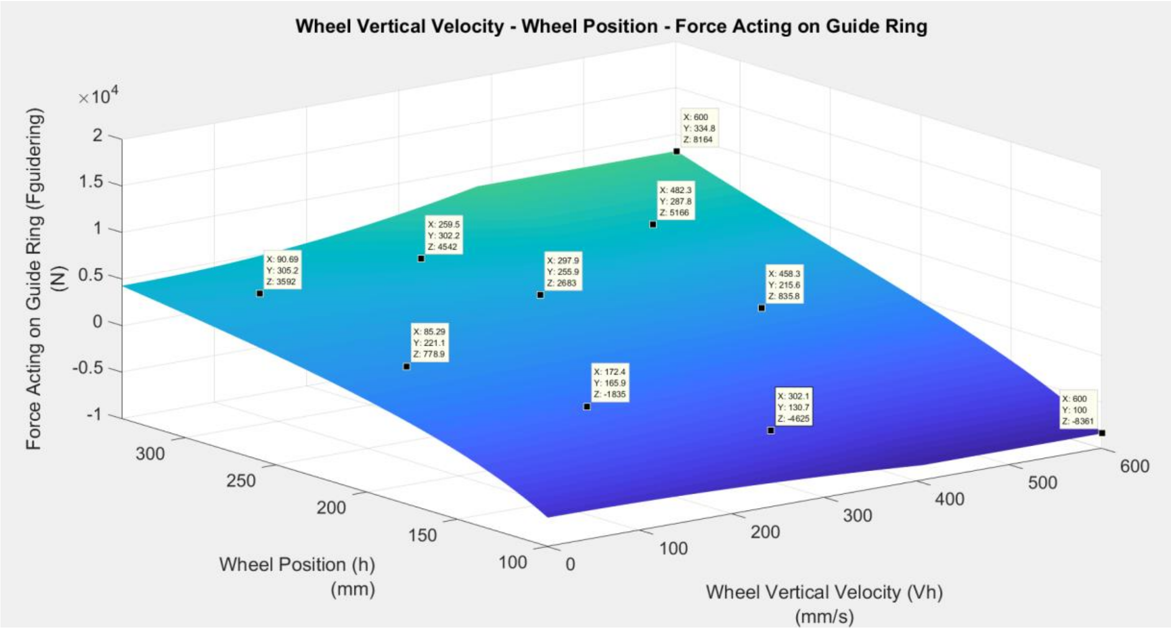


Figure 5.40 Force acting on guide ring plot

5.3. Structural Finite Element Analysis for the Critical Parts

Structural finite element analysis has been performed for the worst case condition of the system. The worst case condition has been assumed that, the system is in bump position and maximum allowed wheel force (78.48 kN) has been applied to the system. Stresses, strains and displacements have been achieved for the critical parts of the HSU. Moreover, the hydraulic piston reaction forces, also the forces acting on the bearings and hydraulic piston guide rings have been performed. Then the forces obtained from the analysis and the forces obtained from GUI have been compared.

The model for the analysis has been created by simplifying the designed 3 CAD model of the HSU. Cylinders and hydraulic block assembly removed from the model as seen in Figure 5.41. Also wheel arm, arm shaft and suspension arm have been modeled as one part as seen in Figure 5.42. The mechanism view of the simplified 3D model has been shown in Figure 5.43.

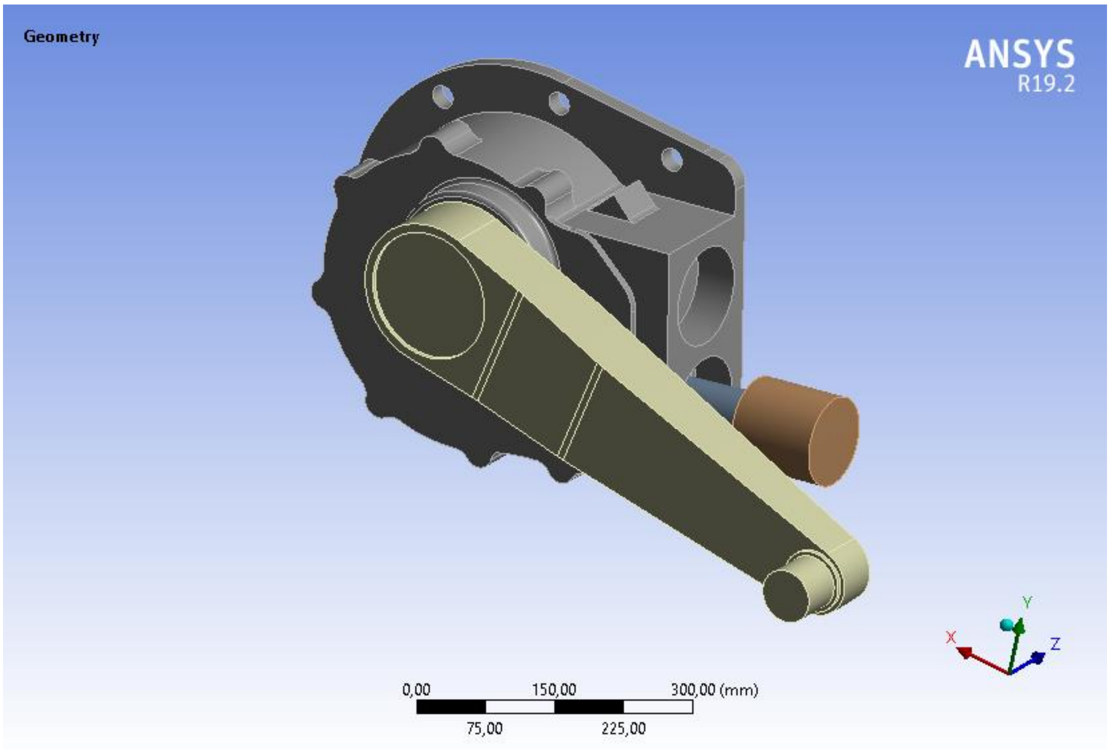


Figure 5.41 Simplified 3D model of the HSU

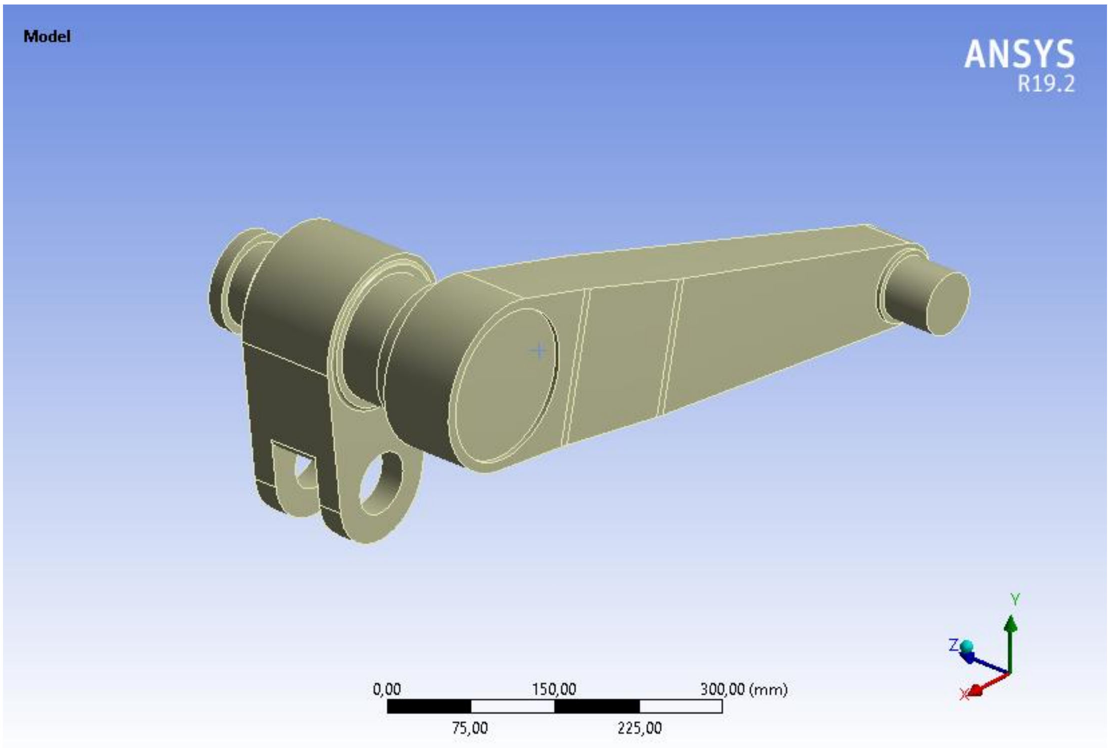


Figure 5.42 Simplified 3D model of the wheel arm – arm shaft – suspension arm

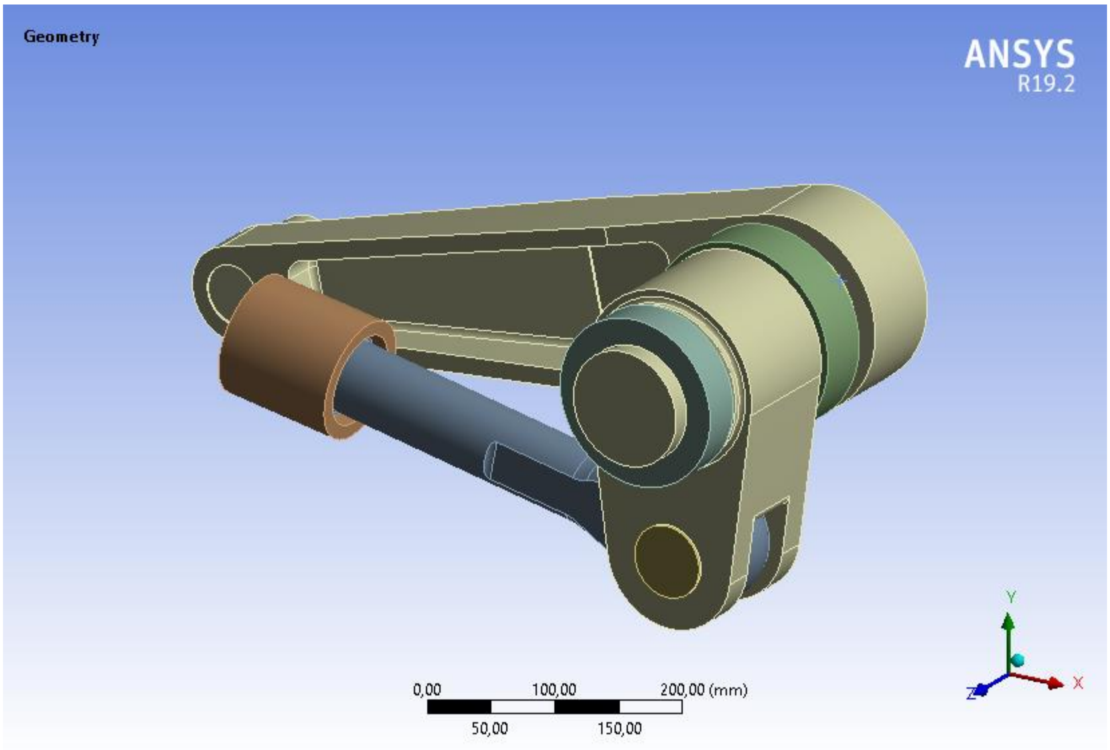


Figure 5.43 Mechanism view of the simplified 3D model

The simplified 3D model has been used for structural analysis by finite element program through ANSYS R19.2. Tetrahedral-quadratic and hexahedral-quadratic elements have been used for meshing the geometry. Totally, 76628 elements and 123257 nodes have been used for meshing. The average mesh quality is 0.76. Meshed view of the simplified 3D model of the HSU has been shown in Figure 5.44 and Figure 5.45.

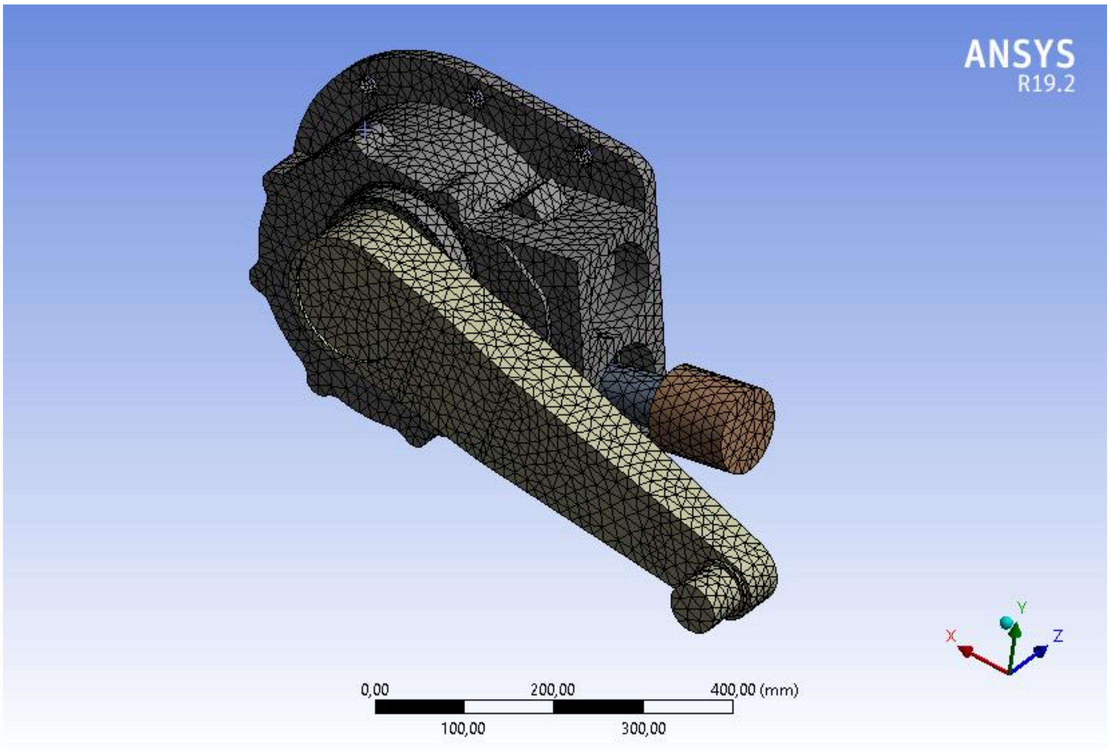


Figure 5.44 Meshed view of the model

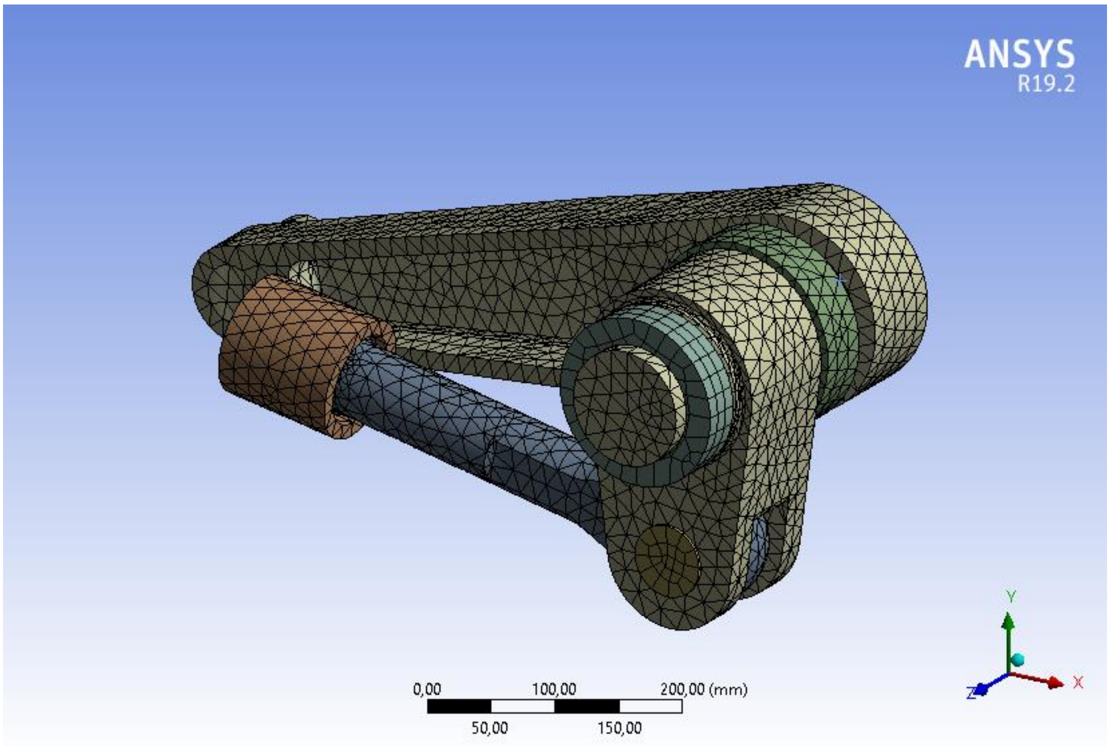


Figure 5.45 Meshed view of the mechanism

The system has been fixed from the stationary casing and the force has been applied from the wheel mounting hub as seen in Figure 5.46.

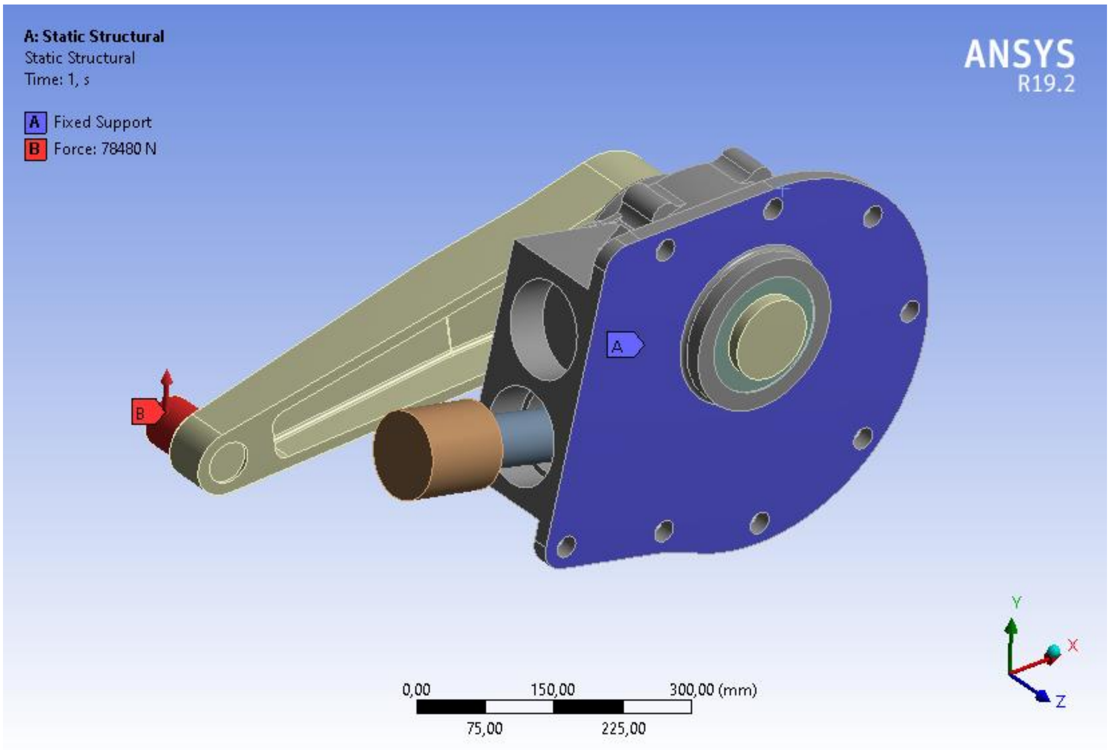


Figure 5.46 Boundary conditions

Stress and strain distributions, on the HSU and on the parts of the HSU have been achieved. Stress distribution on the designed HSU has been shown in Figure 5.47 and Figure 5.48. Stress distributions on the stationary casing and front cover have been shown in Figure 5.49. Stress distributions on the wheel arm, arm shaft and suspension arm have been shown in Figure 5.50. Moreover, stress distributions on the piston rod, hydraulic piston and piston pin have been shown in Figure 5.51, Figure 5.52 and Figure 5.53 respectively.

Furthermore, the displacement values have been obtained from the results of the structural analysis which has been shown in Figure 5.54.

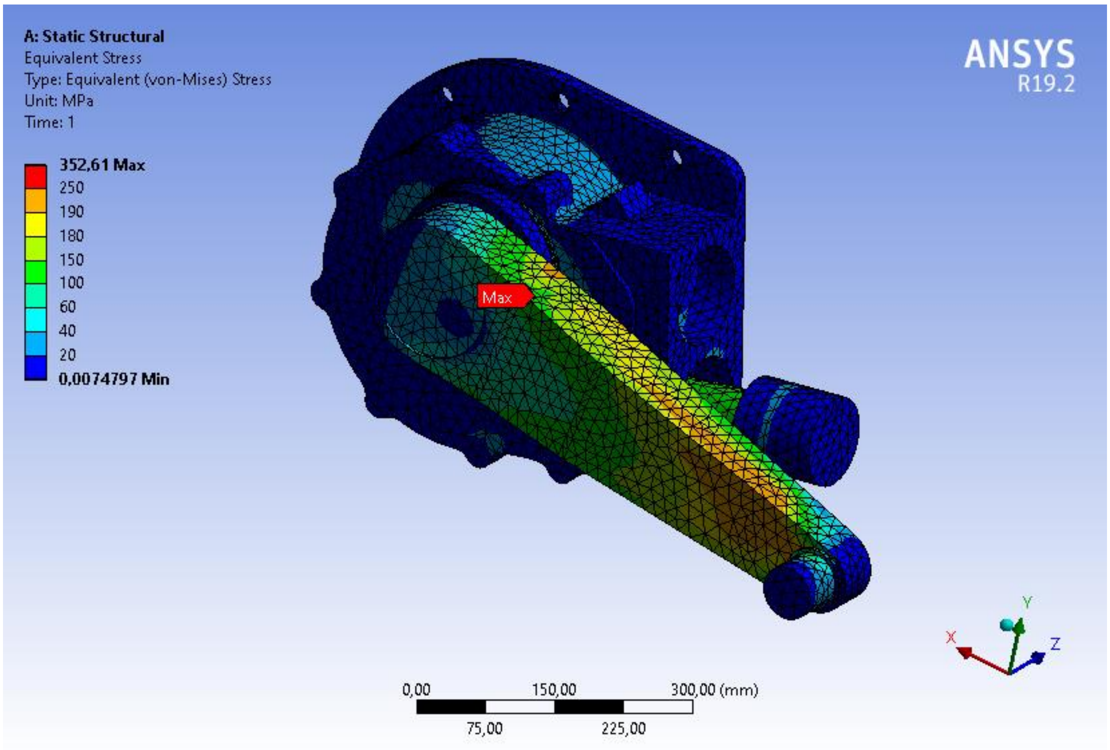


Figure 5.47 Stresses distribution on the HSU

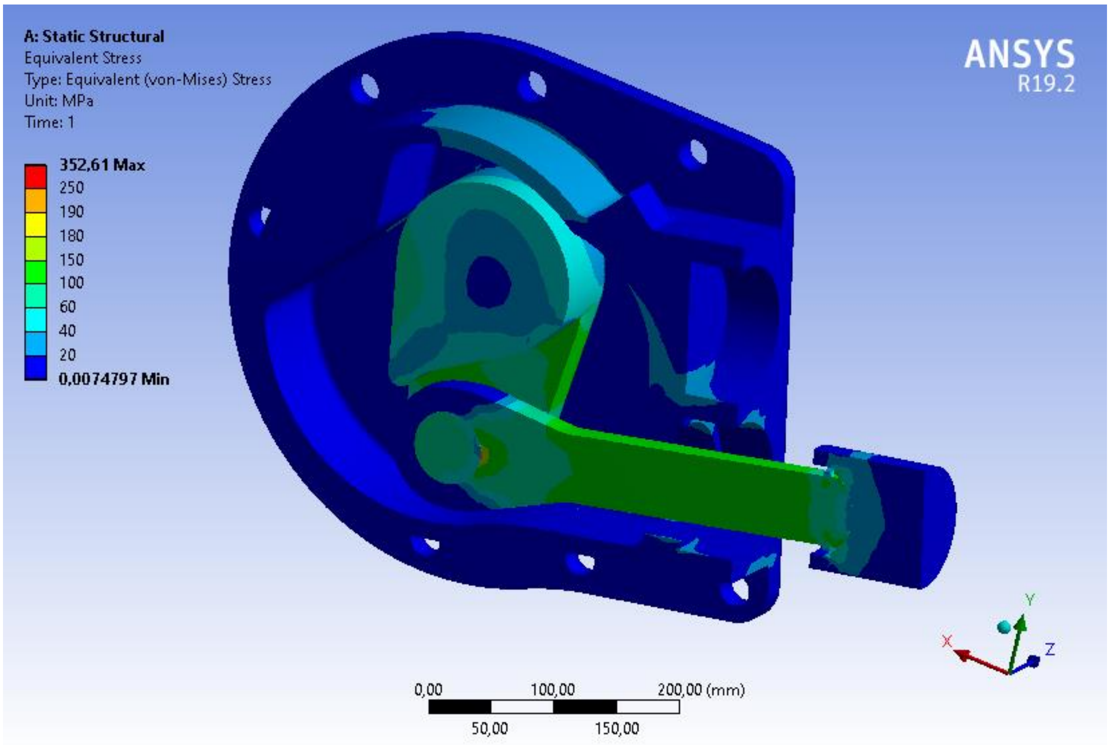


Figure 5.48 Stress distribution on the mechanism

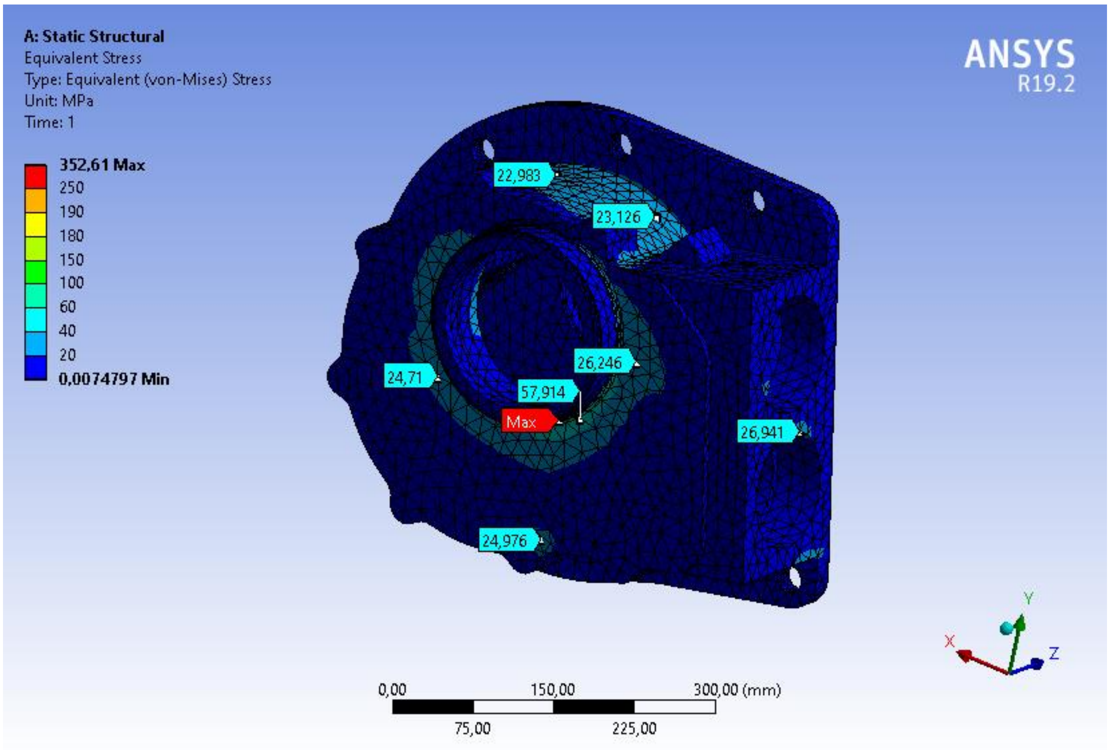


Figure 5.49 Stress distribution on the stationary casing and front cover

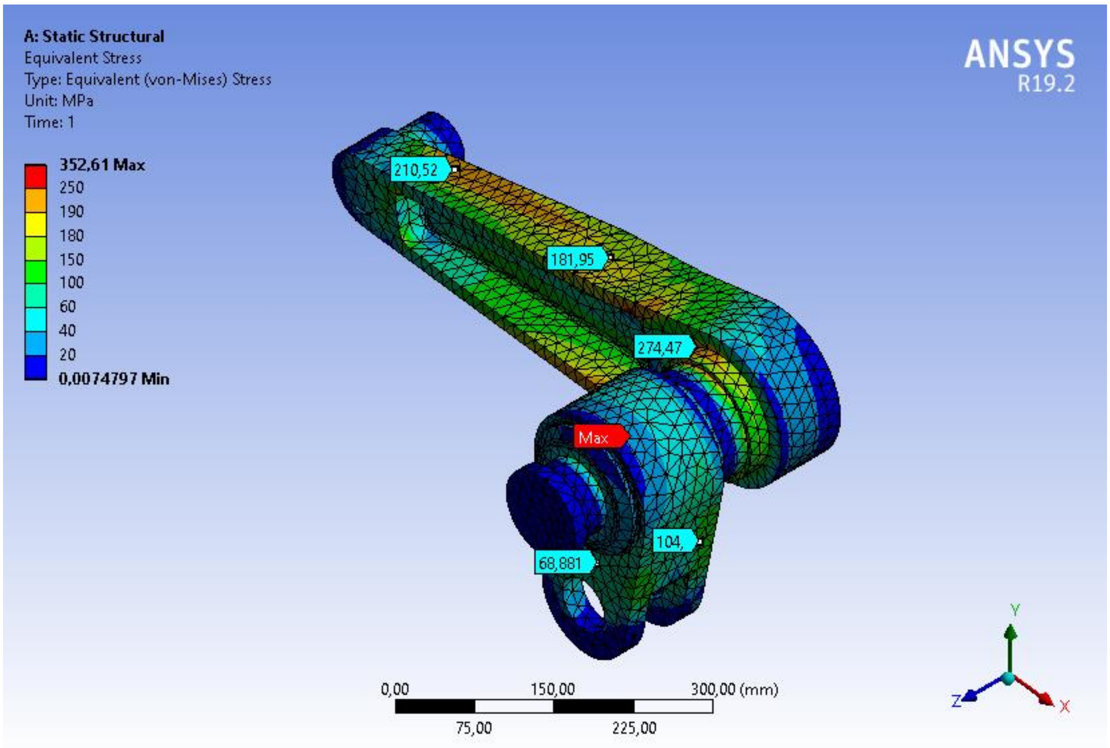


Figure 5.50 Stress distribution on the wheel arm, arm shaft and suspension arm

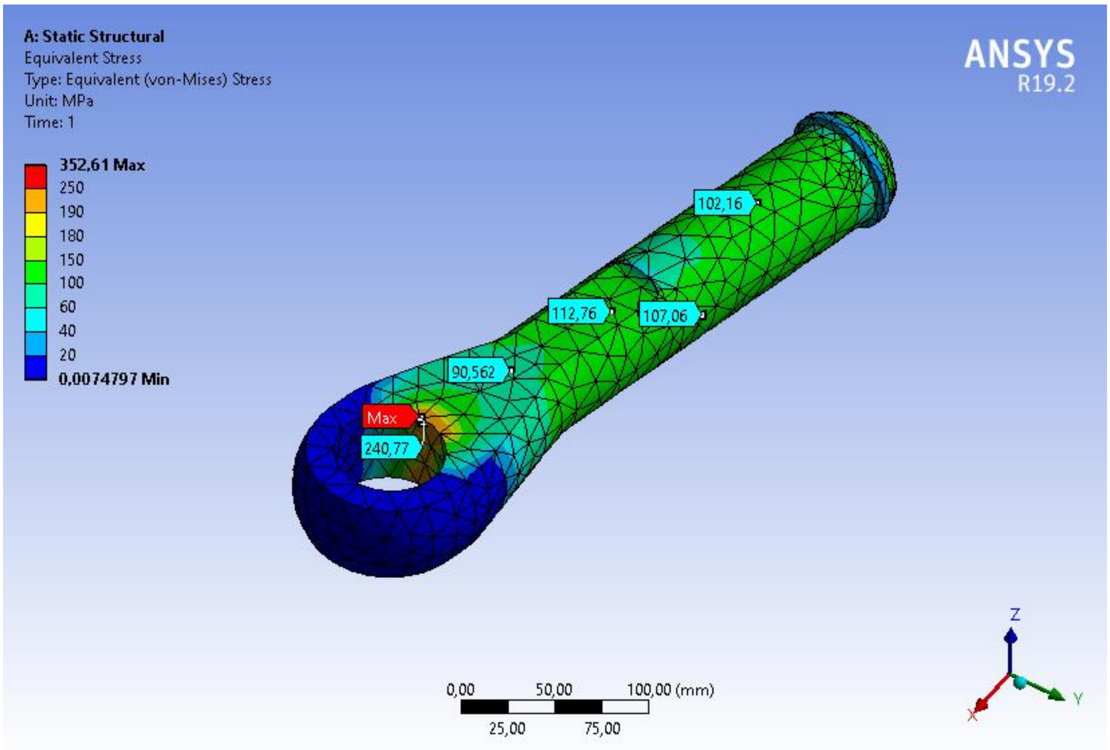


Figure 5.51 Stress distribution on the piston rod

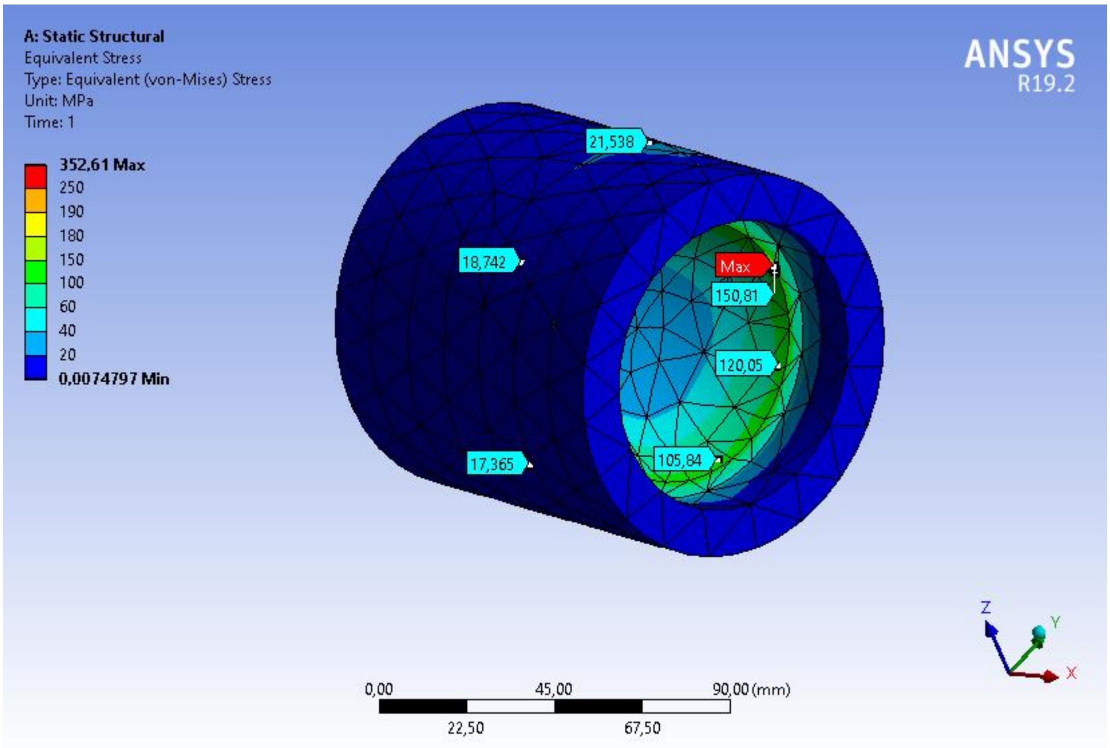


Figure 5.52 Stress distribution on hydraulic piston

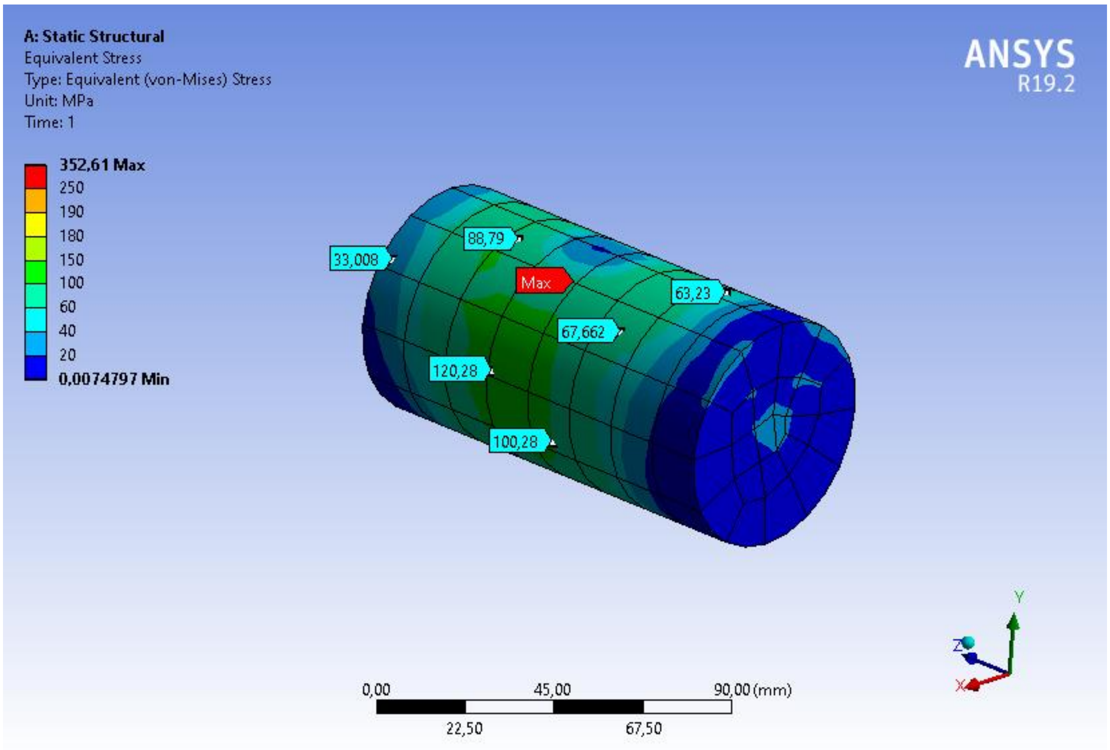


Figure 5.53 Stress distribution on the piston pin

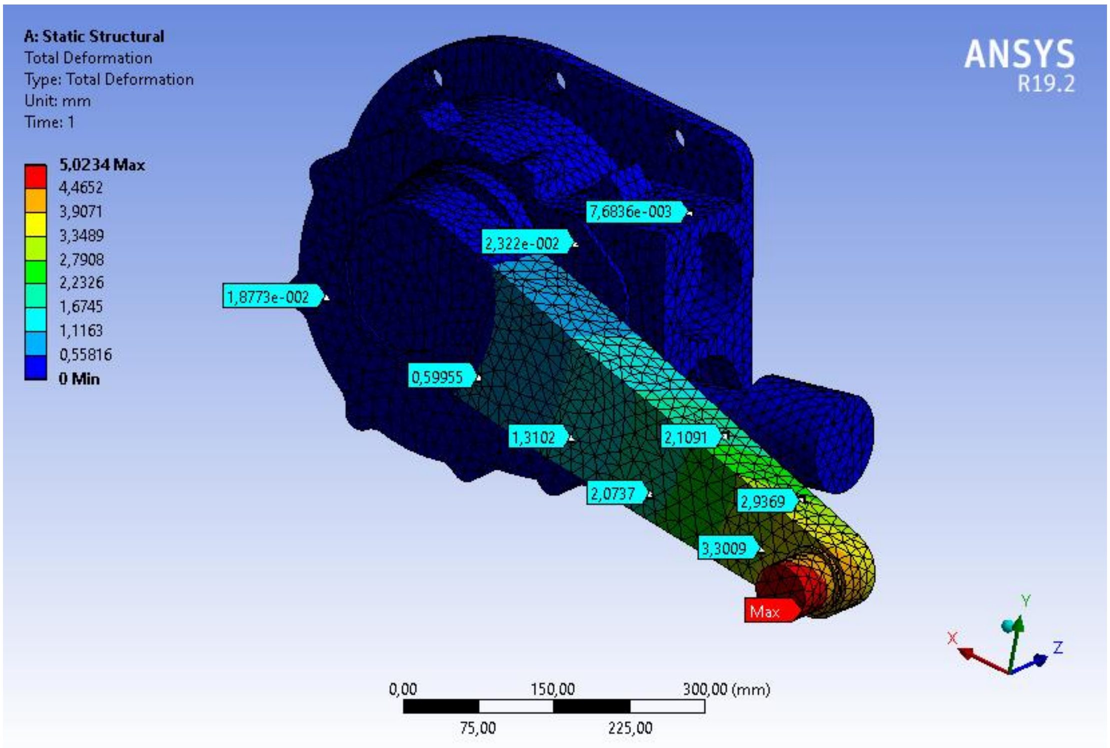


Figure 5.54 Total displacements on the system

Arm shaft has been located on the system by using a double row cylindrical roller bearing (NNCF 4924 CF) and a spherical roller bearing (22216 E) which have been shown in Figure 5.55. The reaction forces acting on the double row cylindrical roller bearing and spherical roller bearing have been achieved from the results of the structural analysis as 155.8 kN and 168.1 kN respectively (Figure 5.56 and Figure 5.57). Moreover, the axial force and the transverse force acting on the hydraulic piston have been achieved as 288.7 kN and 6.9 kN respectively (Figure 5.58 and Figure 5.59).

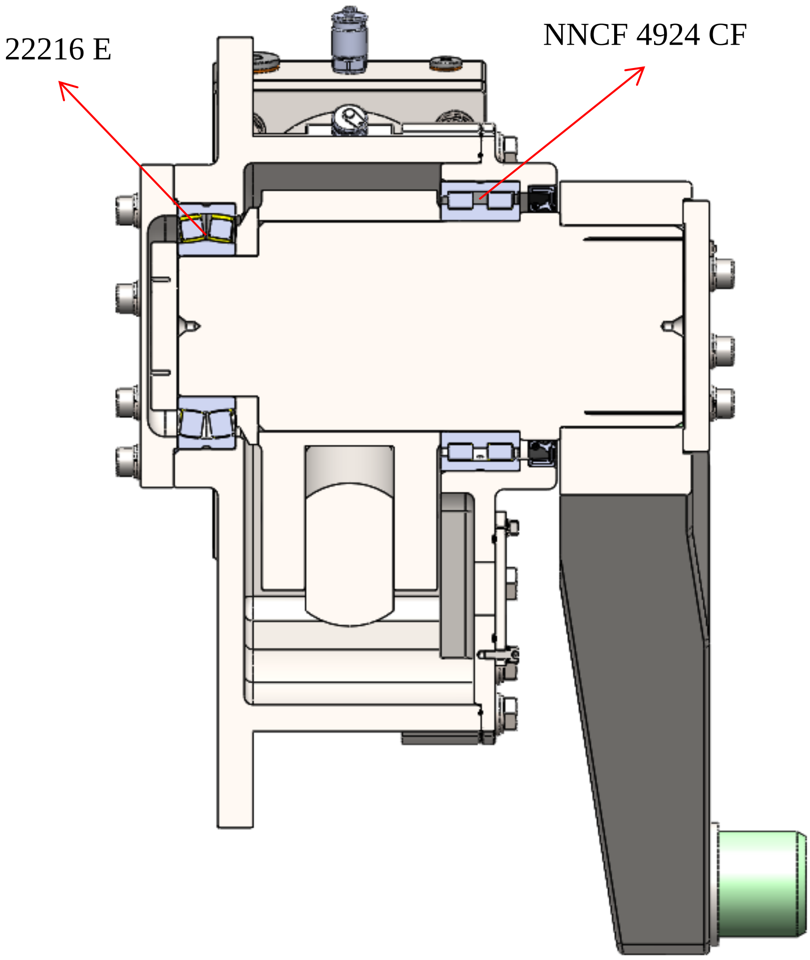
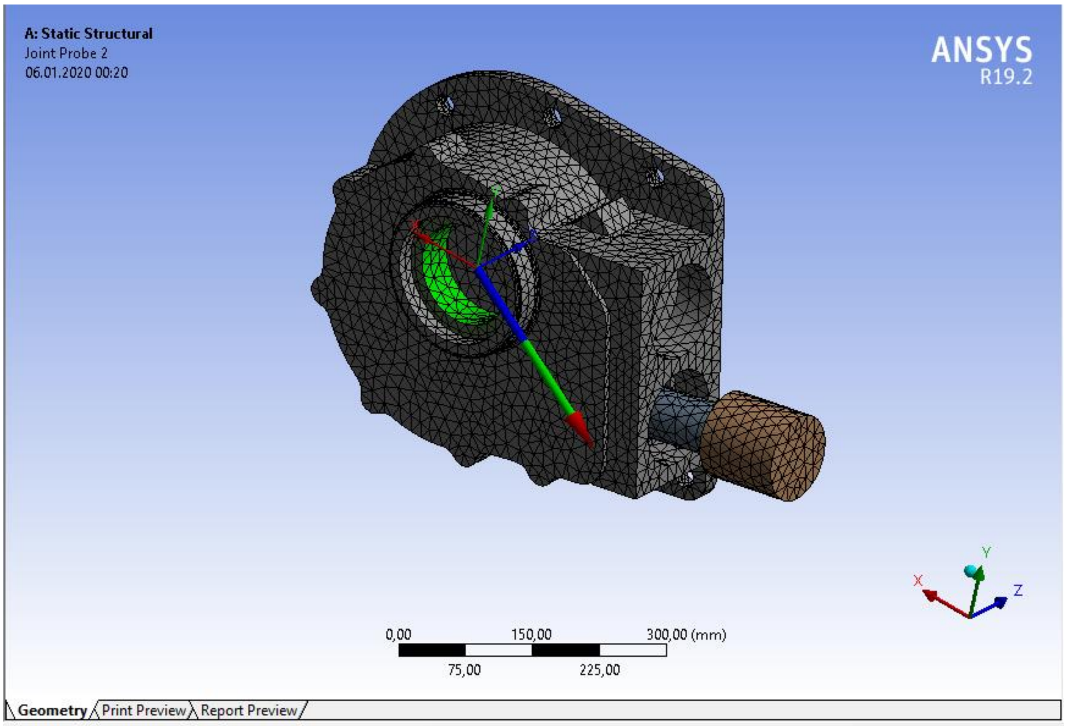


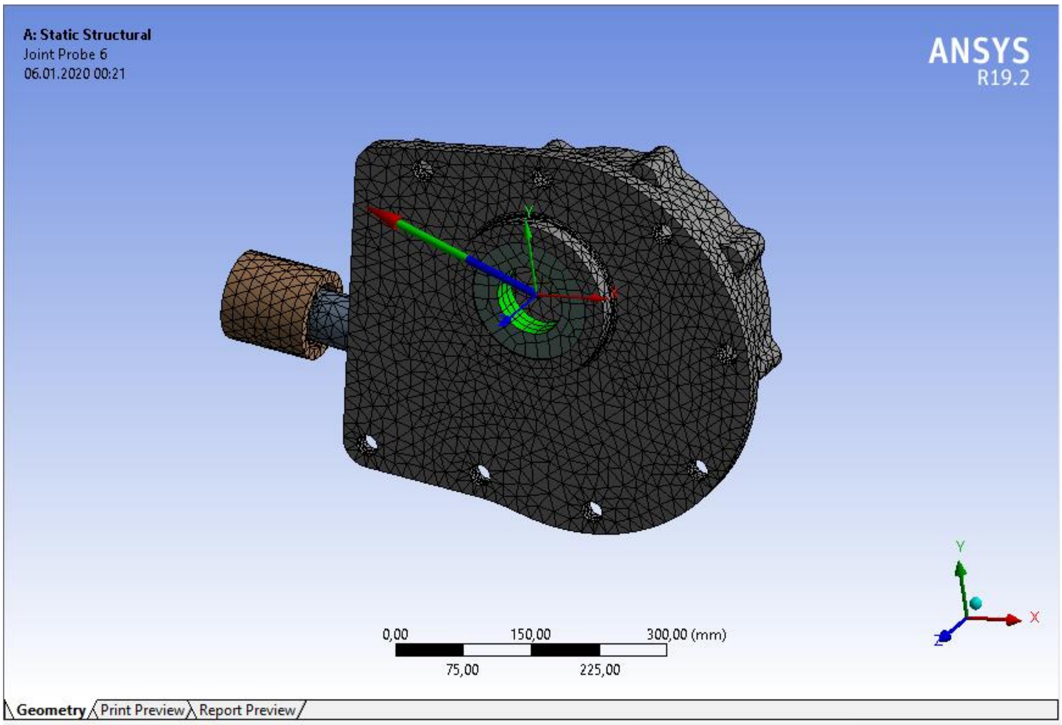
Figure 5.55 Bearings used in the HSU



Tabular Data

	Time [s]	Joint Probe 2 (Total Force X) [N]	Joint Probe 2 (Total Force Y) [N]	Joint Probe 2 (Total Force Z) [N]	Joint Probe 2 (Total Force Total) [N]
1	0,2	-25907	-17241	0,	31119
2	0,4	-51837	-34487	0,	62261
3	0,7	-90779	-60365	0,	1,0902e+005
4	1,	-1,2977e+005	-86254	0,	1,5582e+005

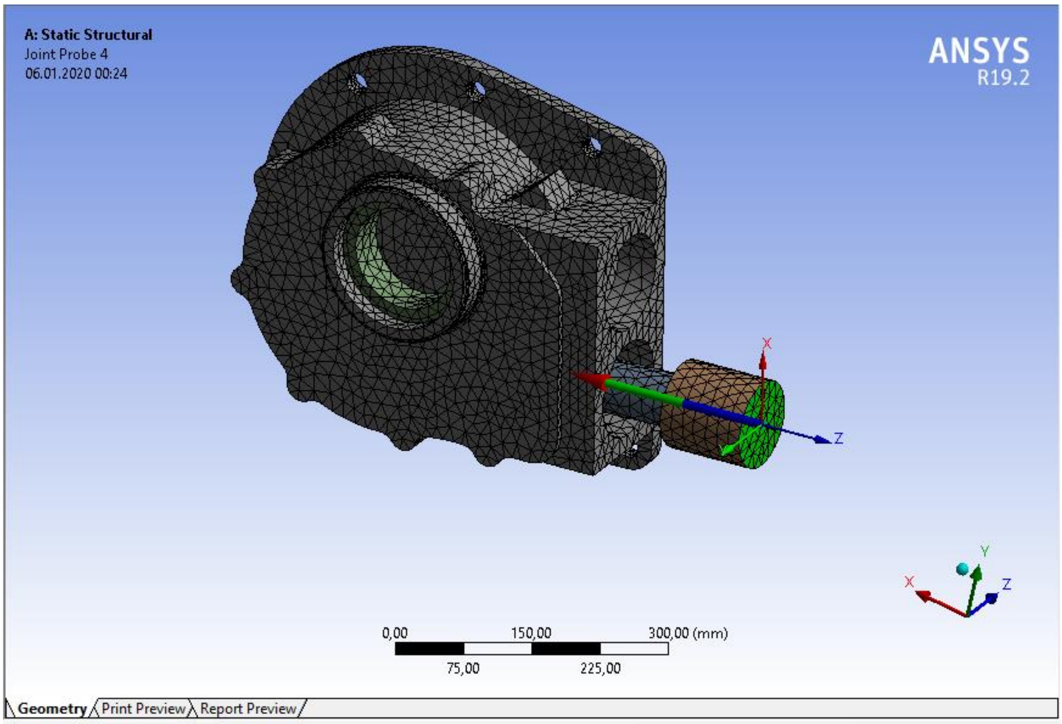
Figure 5.56 Reaction force on the first bearing (NNCF 4924 CF)



Tabular Data

	Time [s]	Joint Probe 6 (Total Force X) [N]	Joint Probe 6 (Total Force Y) [N]	Joint Probe 6 (Total Force Z) [N]	Joint Probe 6 (Total Force Total) [N]
1	0,2	-30374	14399	6,853	33614
2	0,4	-60744	28810	24,969	67230
3	0,7	-1,0629e+005	50449	74,398	1,1766e+005
4	1,	-1,5183e+005	72117	150,	1,6809e+005

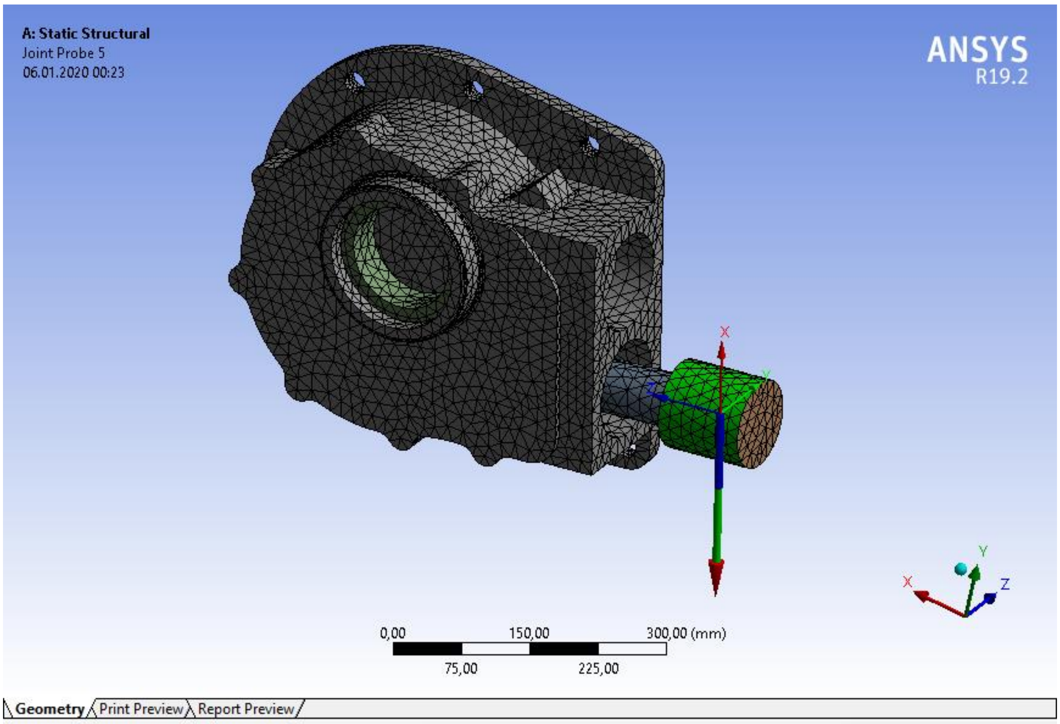
Figure 5.57 Reaction force on the second bearing (22216 E)



Tabular Data

	Time [s]	Joint Probe 4 (Total Force X) [N]	Joint Probe 4 (Total Force Y) [N]	Joint Probe 4 (Total Force Z) [N]	Joint Probe 4 (Total Force Total) [N]
1	0,2	0,	0,	-57713	57713
2	0,4	0,	0,	-1,1545e+005	1,1545e+005
3	0,7	0,	0,	-2,0209e+005	2,0209e+005
4	1,	0,	0,	-2,8878e+005	2,8878e+005

Figure 5.58 Axial force acting on the hydraulic piston



Tabular Data

	Time [s]	Joint Probe 5 (Total Force X) [N]	Joint Probe 5 (Total Force Y) [N]	Joint Probe 5 (Total Force Z) [N]	Joint Probe 5 (Total Force Total) [N]
1	0,2	-1374,8	-5,5291	0,	1374,8
2	0,4	-2752,6	-19,671	0,	2752,7
3	0,7	-4825,3	-58,161	0,	4825,7
4	1,	-6905,1	-116,84	0,	6906,1

Figure 5.59 Transverse force acting on the hydraulic piston

The axial and the transverse forces acting on the hydraulic piston obtained from the structural analysis and the developed GUI have been compared in Table 5.3. As seen from the table, the results are consistent. (The transverse force acting on the hydraulic piston obtained from the GUI has been shown in Figure 5.60.)

Table 5.3 Comparison of the GUI results and the structural analysis results

Parameter	GUI Result	Analysis Result
Axial force on hydraulic piston	288.4 kN	288.8 kN
Transverse force on hydraulic piston	6.9 kN	6.9 kN

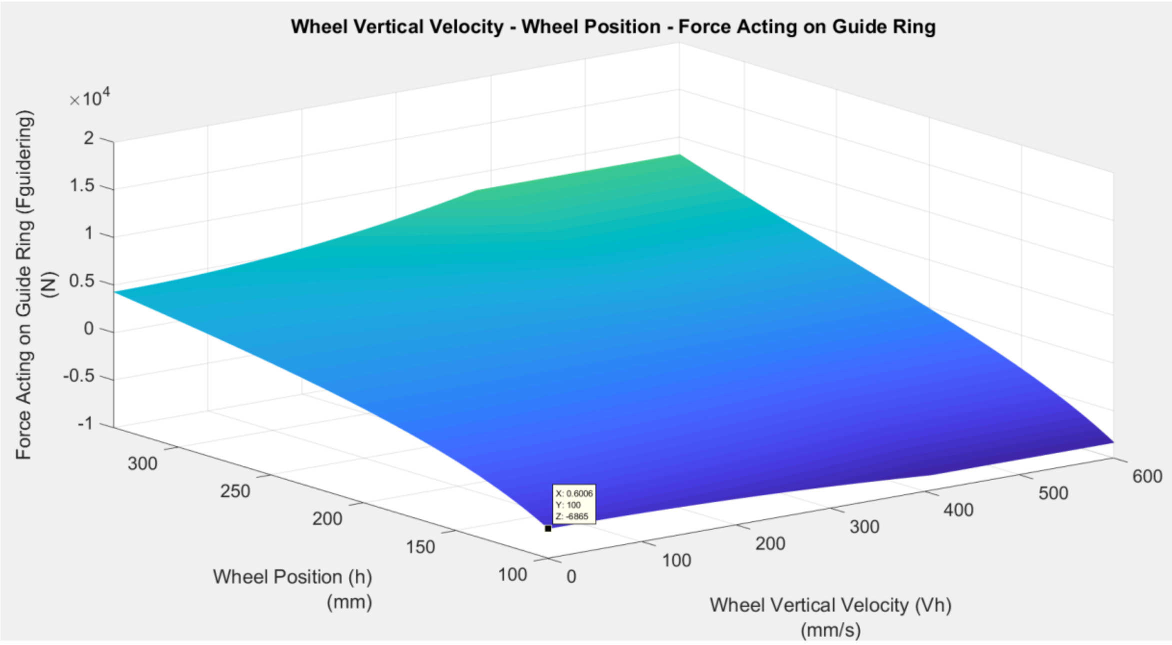


Figure 5.60 Transverse force acting on the piston (GUI output)

5.4. Material Selection Criteria

It is known that, the selection of materials for the HSU parts, play critical role for the design process. Stress values on the parts of the HSU and the forces acting on the piston and bearings have been determined for the most critical loading condition of the system by using the structural analysis results.

The computed stress results are the primary criterion for the selection of the materials of the HSU parts. Also machinability, weldability and heat treatment capabilities of the materials are other critical criteria for the selection of the types of materials. Maximum stresses on the critical parts of the HSU and the chosen materials have been tabulated in Table 5.4.

Table 5.4 Maximum stresses on the critical parts and chosen materials

Part of the HSU	**Maximum Stress**	**Chosen Material**	**Yield Strength of the Material**
Stationary Casing	58 MPa	1.1191 (C45E)	565 MPa
Front Cover	68 MPa	1.1191 (C45E)	565 MPa
Wheel Arm	210 MPa	1.0570 (S355J2G3)	315 MPa
Arm Shaft	353 MPa	1.6587 (18CrNiMo7-6)	785 MPa
Suspension Arm	353 MPa	1.6587 (18CrNiMo7-6)	785 MPa
Piston Rod	241 MPa	1.1191 (C45E)	565 MPa
Hydraulic Piston	151 MPa	1.1191 (C45E)	565 MPa
Piston Pin	120 MPa	1.1191 (C45E)	565 MPa

The types of materials chosen for the parts of the HSU have been given in bill of materials (BOM) and drawings of the parts. Also, the heat treatment details for the parts have been given in drawings of the parts.

5.5. Bill of Materials (BOM) and Drawings

Bill of materials has been prepared according to the designed HSU. The prepared BOM for the HSU has been shown in Table 5.5.

Table 5.5 Bill of materials of the designed HSU

NO	PART NUMBER	PART NAME	MATERIAL	WEIGHT (kg)	QTY
1	001-01000-00-R00	SUSPENSION ASSEMBLY	ASSEMBLY	195.83	1
1.1	001-01000-01-R00	STATIONARY CASING	1.1191 (C45E)	62.35	1
1.2	001-01000-02-R00	PISTON PIN	1.1191 (C45E)	2.46	1
1.3	001-01000-03-R00	PISTON PIN ANCHORAGE PLATE	1.0402 (C22)	0.07	1
1.4	001-01000-04-R00	PISTON CYLINDER	1.0044 (S275JR)	5.49	2
1.5	001-01000-05-R00	HYDRAULIC BLOCK CAP	1.1191 (C45E)	3.87	1
1.6	001-01000-06-R00	BEARING CAP	1.1191 (C45E)	0.75	1
1.7	001-01000-07-R00	REAR CAP	1.1191 (C45E)	2.47	1
1.8	001-01000-08-R00	MAINTENANCE CAP	1.0037 (S235JR)	0.82	1
1.9	001-01100-00-R00	SUSPENSION ARM ASSEMBLY	ASSEMBLY	79.20	1
1.9.1	001-01100-01-R00	FRONT COVER	1.1191 (C45E)	14.54	1
1.9.2	001-01100-02-R00	ARM SHAFT	1.6587 (18CrNiMo7-6)	21.93	1
1.9.3	001-01100-03-R00	LOCATING SHIM	1.1191 (C45E)	0.77	1
1.9.4	001-01100-04-R00	SUSPENSION ARM	1.6587 (18CrNiMo7-6)	12.22	1
1.9.5	001-01100-05-R00	WHEEL ARM	1.0570 (S355J2G3)	26.77	1
1.9.5.1	001-01100-05-R00-01	WHEEL ARM BODY	1.0570 (S355J2G3)	24.86	1
1.9.5.2	001-01100-05-R00-02	WHEEL ARM PIN	1.0570 (S355J2G3)	1.92	1
1.9.6	001-01100-06-R00	WHEEL ARM CAP	1.1191 (C45E)	1.73	1
1.9.7	001-01100-07-R00	WHEEL ARM KEY	1.1191 (C45E)	0.29	2
1.9.8	BEARING_NNCF_4924_CV	COTS ITEM	-	-	1
1.9.9	ROTARY_SEAL_130x160x15	COTS ITEM	-	-	1
1.9.10	WASHER_DIN 125_M10	COTS ITEM	-	-	6
1.9.11	SPRING_WASHER_DIN 128_M10	COTS ITEM	-	-	6
1.9.12	BOLT_DIN 912_M10x40	COTS ITEM	-	-	6

1.10	001-01200-00-R00	HYDRAULIC PISTON ASSEMBLY	ASSEMBLY	13.68	1
1.10.1	001-01200-01-R00	PISTON ROD	1.1191 (C45E)	8.53	1
1.10.2	001-01200-02-R00	PISTON ROD BUSHING	2.0966 (CuAl10Ni5Fe4)	0.38	1
1.10.3	001-01200-03-R00	PISTON FRONT CAP	1.1191 (C45E)	0.11	2
1.10.4	001-01200-04-R00	PISTON FRICTION BUSHING	1.7225 (42CrMo4)	0.60	1
1.10.5	001-01200-05-R00	HYDRAULIC PISTON	1.1191 (C45E)	3.85	1
1.10.6	SPRING_WASHER_DIN 128_M5	COTS ITEM	-	-	8
1.10.7	BOLT_DIN 912_M5x16	COTS ITEM	-	-	8
1.10.8	WASHER_DIN 125_M5	COTS ITEM	-	-	8
1.10.9	TRELLEBORG_TURCON_GLYD_RING_PG4201000-M12N	COTS ITEM	-	-	2
1.10.10	TRELLEBORG_SLYDRING_GP7501000	COTS ITEM	-	-	2
1.11	001-01300-00-R00	HYDRO-GAS PISTON ASSEMBLY	ASSEMBLY	3.65	1
1.11.1	001-01300-01-R00	GAS SIDE PISTON	1.1191 (C45E)	3.57	1
1.11.2	TRELLEBORG_TURCON_GLYD_RING_PG4201000-M12N	COTS ITEM	-	-	2
1.11.3	TRELLEBORG_SLYDRING_GP7501000	COTS ITEM	-	-	2
1.12	001-01400-00-R00	HYDRAULIC BLOCK ASSEMBLY	ASSEMBLY	14.60	1
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1.12.3	PRESSURE_RELIEF_VALVE_WANDFLUH_BCAPM22-420	COTS ITEM	-	-	1
1.12.4	CONNECTOR_SKK20-G1_4_PB	COTS ITEM	-	-	1
1.12.5	PLUG_DIN 908_G3_4	COTS ITEM	-	-	1
1.12.6	PLUG_DIN 908_G1_2	COTS ITEM	-	-	2
1.12.7	PLUG_DIN 908_G1_4	COTS ITEM	-	-	1
1.13	BEARING_22216_E	COTS ITEM	-	-	1
1.14	CONNECTOR_SKK20-G1_4_PB	COTS ITEM	-	-	1
1.15	O-RING_117,07x3,53	COTS ITEM	-	-	2
1.16	O-RING_107,54x3,53	COTS ITEM	-	-	2
1.17	O-RING_139,37x2,62	COTS ITEM	-	-	1
1.18	O-RING_1,78xL1118	COTS ITEM	-	-	1
1.19	WASHER_DIN 125_M12	COTS ITEM	-	-	18

1.20	SPRING_WASHER_DIN 128_M12	COTS ITEM	-	-	18
1.21	BOLT_DIN 931_M12x50	COTS ITEM	-	-	8
1.22	BOLT_DIN 931_M12x40	COTS ITEM	-	-	10
1.23	WASHER_DIN 125_M10	COTS ITEM	-	-	10
1.24	SPRING_WASHER_DIN 128_M10	COTS ITEM	-	-	10
1.25	BOLT_DIN 912_M10x25	COTS ITEM	-	-	6
1.26	BOLT_DIN 912_M10x40	COTS ITEM	-	-	8
1.27	O-RING_1,78xL447	COTS ITEM	-	-	1
1.28	WASHER_DIN 125_M5	COTS ITEM	-	-	7
1.29	SPRING_WASHER_DIN 128_M5	COTS ITEM	-	-	7
1.30	BOLT_DIN 912_M5x14	COTS ITEM	-	-	7
1.31	GREASE_NIPPLE_DIN 71412_M12x1.5	COTS ITEM	-	-	1

Detailed manufacturing drawings for the parts and assembly drawings for assemblies of the designed HSU have been given in Appendix 1.

6. CONCLUSION

Suspension systems are one of the most critical components for the ride dynamics and comfort performance of a vehicle. Also, off road performance and mobility of the high tonnage vehicles directly depend on the suspension system of the vehicle. High tonnage vehicles such as tanks, tracked howitzers and fighting vehicles in military applications generally use two types of suspension systems. Those are torsion bars and hydraulic suspension systems. Most of the tracked military vehicles which require high mobility and off road performance together with comfortableness and speed preferred to use torsion bar suspension systems due to low cost and low maintenance. But, hit accuracy and long term combat requirements brought the necessity of using more comfortable and higher off road performance for these types of vehicles. The solution to these new requirements is found by the hydro-pneumatic suspension systems.

In this thesis, a parametric design tool is aimed to be developed for manufacturing hydro-pneumatic suspension system which may serve for all type of vehicles with different tonnages. For preliminary design of a hydro-pneumatic suspension system, a Graphical User Interface (GUI) has been developed for the input parameters and getting output design parameters. This enables to process the input-output parameters fast and easily. Thus, the predesign process time for designing a hydro-pneumatic suspension unit has been reduced significantly. Essentially, the back side of the GUI runs the developed analytical solver by using input parameters and provides output parameters required for designing a hydro-pneumatic suspension unit. For this tool, a mathematical model has been developed which contains necessary equations for developing a hydro-pneumatic suspension unit and then, kinematics, spring characteristics and damper characteristics of a hydro-pneumatic suspension unit have been analyzed.

In order to verify the mathematical model with finite element analysis, required input parameters for a 24 tones-example have been specified and output parameters and plots by the developed graphical user interface have been generated for detailed design of a hydro-pneumatic suspension unit.

Finally, structural finite element analysis has been performed for the critical parts of the system. Stress and strain distributions on the critical parts have been obtained. Furthermore, the reaction forces on the bearings and hydraulic piston have been obtained from the structural analysis results. The axial and transverse forces acting on the hydraulic piston, obtained from the analysis results and the graphical user interface have been compared and it has been seen that the results are consistent to each other.

After verification, a technical data package based on selected vehicle data has been performed which involves 3D CAD model of the designed HSU, bill of materials (COTS items included), assembly and part drawings of the system. Thus, a verified developing tool has been settled for further designs.

6.1. Future Work

A prototype of the designed hydro-pneumatic suspension unit might be prepared and tested. By using the test results, the developed mathematical model and designed 3D CAD model might be improved.

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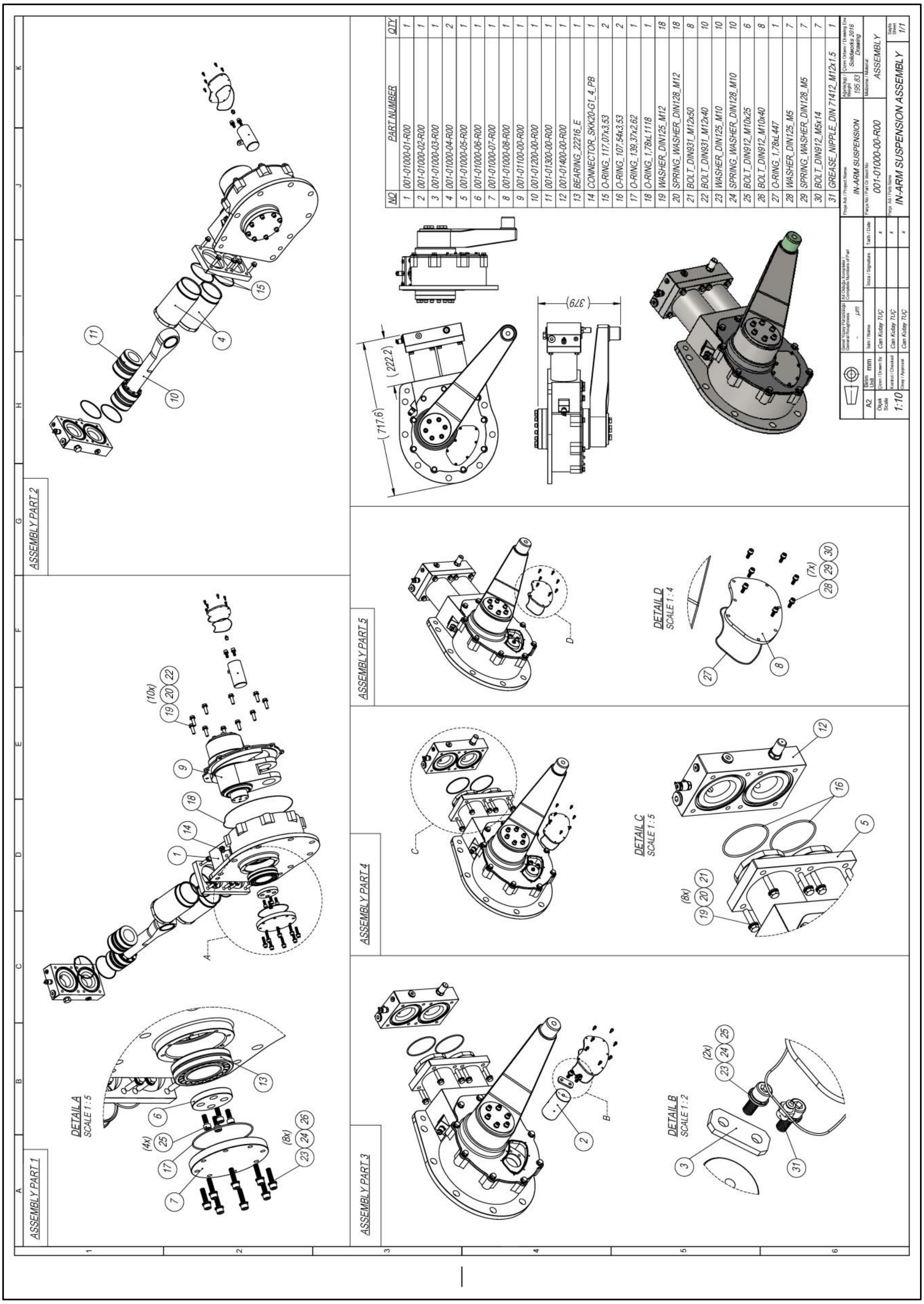
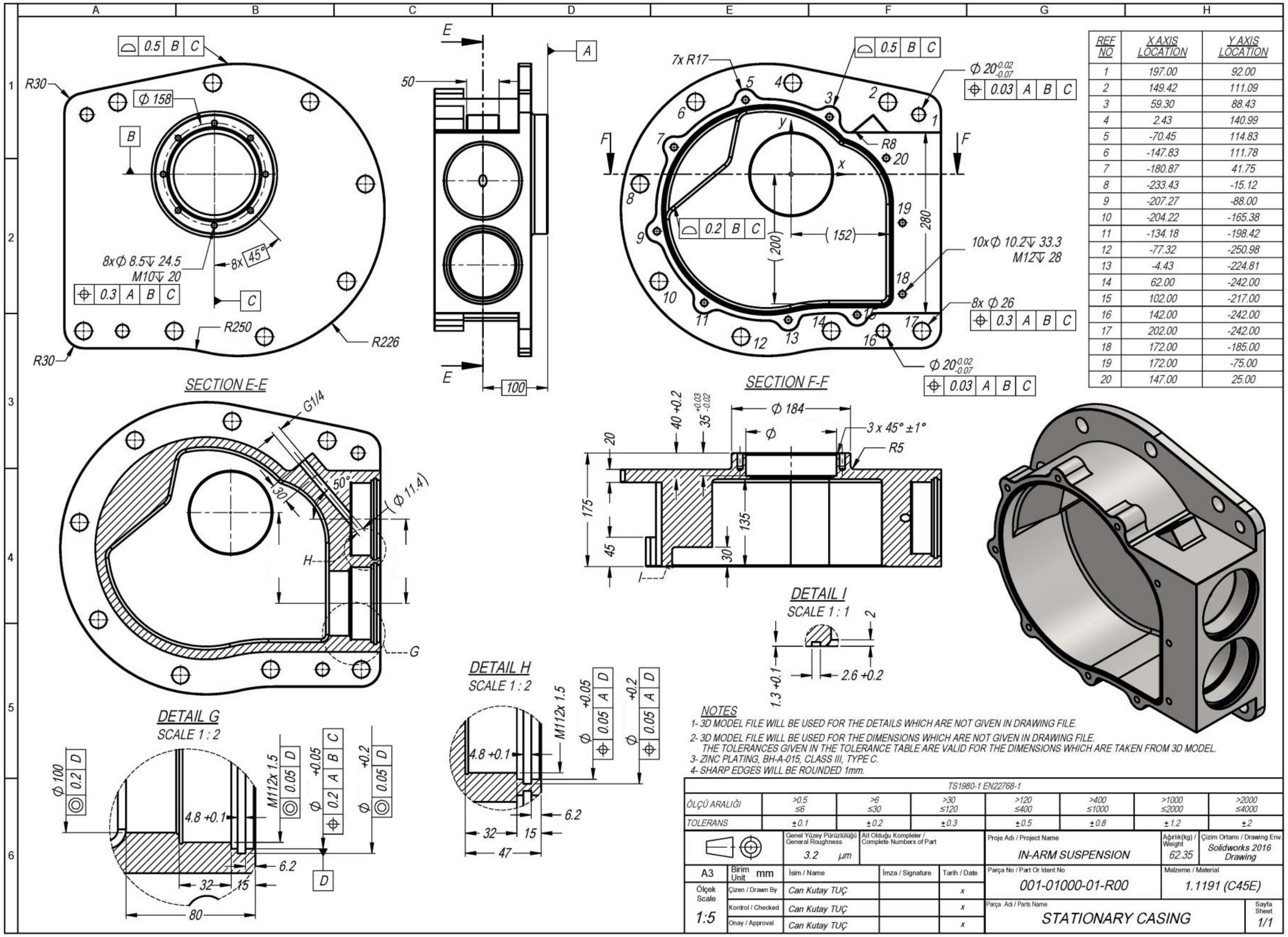
APPENDIX

APPENDIX 1 : TECHNICAL DRAWINGS OF THE DESIGNED HSU





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NOTES
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2- 3D MODEL FILE WILL BE USED FOR THE DIMENSIONS WHICH ARE NOT GIVEN IN DRAWING FILE. THE TOLERANCES GIVEN IN THE TOLERANCE TABLE ARE VALID FOR THE DIMENSIONS WHICH ARE TAKEN FROM 3D MODEL.
3- ZINC PLATING, BH-A-015, CLASS III, TYPE C.
4- SHARP EDGES WILL BE ROUNDED 1mm.

TS1980-1 EN22768-1

ÖLÇÜ ARALIĞI	>0.5 ≤6	>6 ≤30	>30 ≤120	>120 ≤400	>400 ≤1000	>1000 ≤2000	>2000 ≤4000
TOLERANS	±0.1	±0.2	±0.3	±0.5	±0.8	±1.2	±2

Genel Yüzey Pürüzlülüğü / General Roughness: 3.2 μm
Ait Olduğu Kompleler / Complete Numbers of Part
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Ağırlık(kg) / Weight: 62.35
Çizim Ortamı / Drawing Env.: Solidworks 2016 Drawing
A3 — Birim Unit: mm
Ölçek Scale: 1:5

	İsim / Name	İmza / Signature	Tarih / Date
Çizen / Drawn By	Can Kutay TUÇ		x
Kontrol / Checked	Can Kutay TUÇ		x
Onay / Approval	Can Kutay TUÇ		x

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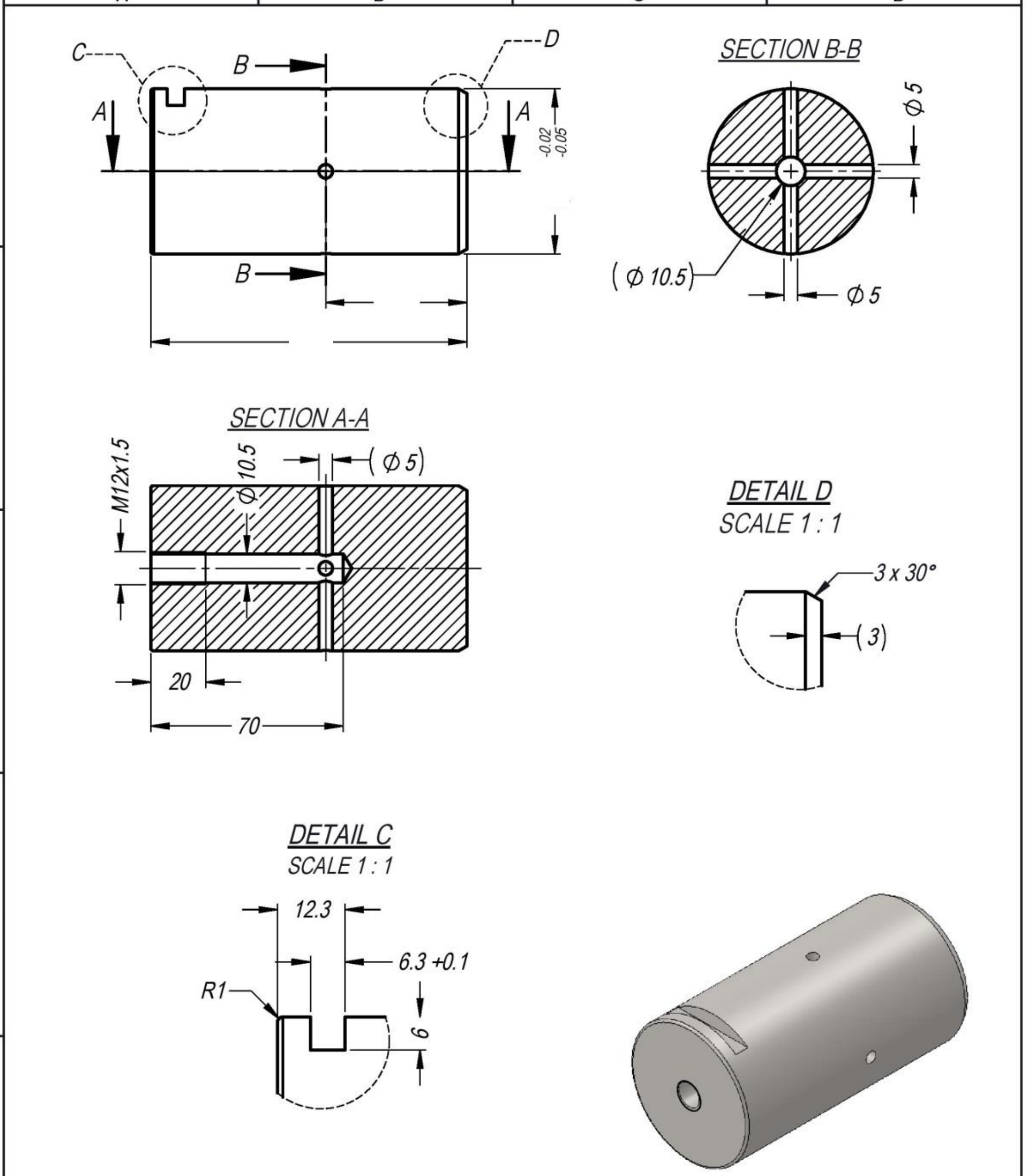
Malzeme / Material: 1.1191 (C45E)
Parça Adı / Parts Name: STATIONARY CASING
Sayfa Sheet: 1/1



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THE TOLERANCES GIVEN IN THE TOLERANCE TABLE ARE VALID FOR THE DIMENSIONS WHICH ARE TAKEN FROM 3D MODEL.

3- ZINC PLATING, BH-A-015, CLASS III, TYPE C.

TS1980-1 EN22768-1

ÖLÇÜ ARALIĞI	>0.5 ≤6	>6 ≤30	>30 ≤120	>120 ≤400	>400 ≤1000	>1000 ≤2000	>2000 ≤4000
TOLERANS	±0.1	±0.2	±0.3	±0.5	±0.8	±1.2	±2

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	Onay / Approval	Can Kutay TUÇ		X

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001-01000-02-R00	1.1191 (C45E)

Parça Adı / Parts Name	Sayfa Sheet
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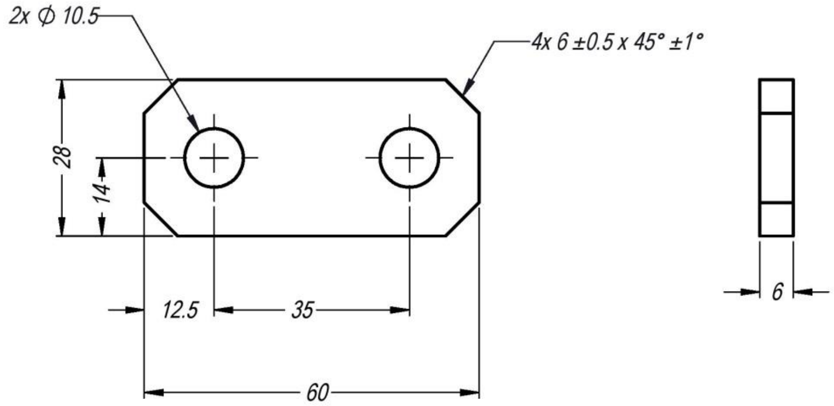

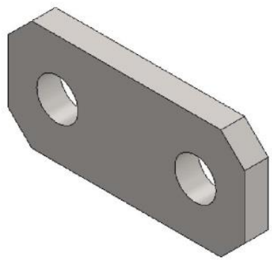

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THE TOLERANCES GIVEN IN THE TOLERANCE TABLE ARE VALID FOR THE DIMENSIONS WHICH ARE TAKEN FROM 3D MODEL.
3- ZINC PLATING, BH-A-015, CLASS III, TYPE C.

TS1980-1 EN22768-1							
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TOLERANS	±0.1	±0.2	±0.3	±0.5	±0.8	±1.2	±2

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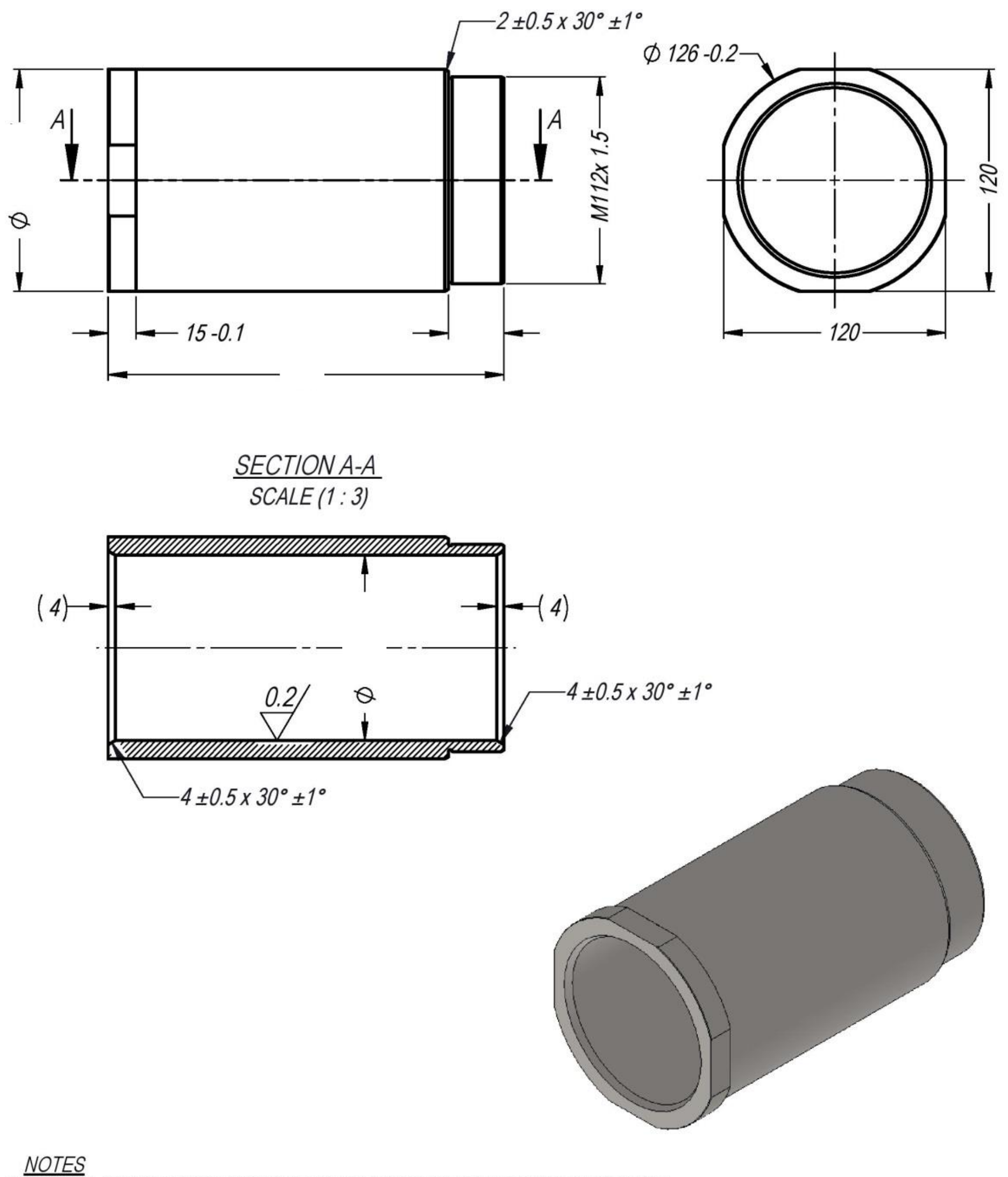
	Onay / Approval	Can Kutay TUÇ		X

Parça No / Part Or Ident No: 001-01000-03-R00

Malzeme / Material: 1.0402 (C22)

Parça Adı / Parts Name: PISTON PIN ANCHORAGE PLATE

Sayfa Sheet: 1/1



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2- 3D MODEL FILE WILL BE USED FOR THE DIMENSIONS WHICH ARE NOT GIVEN IN DRAWING FILE.
THE TOLERANCES GIVEN IN THE TOLERANCE TABLE ARE VALID FOR THE DIMENSIONS WHICH ARE TAKEN FROM 3D MODEL.

3- ZINC PLATING, BH-A-015, CLASS III, TYPE C.

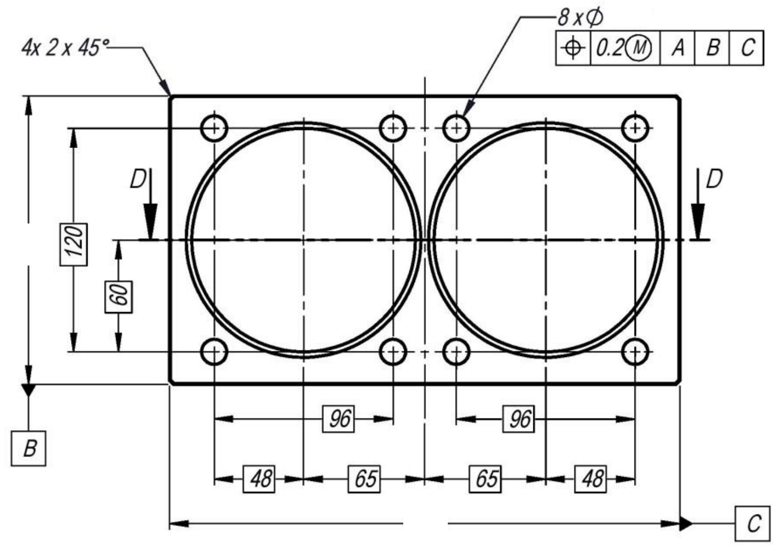
TS1980-1 EN22768-1

ÖLÇÜ ARALIĞI	>0.5 ≤6	>6 ≤30	>30 ≤120	>120 ≤400	>400 ≤1000	>1000 ≤2000	>2000 ≤4000
TOLERANS	±0.1	±0.2	±0.3	±0.5	±0.8	±1.2	±2

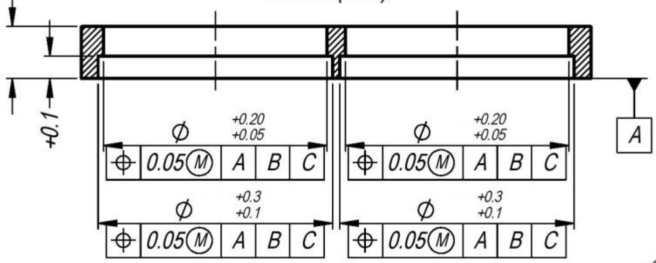
Genel Yüzey Pürüzlülüğü / General Roughness: 3.2 μm	Ait Olduğu Kompleler / Complete Numbers of Part	Proje Adı / Project Name: IN-ARM SUSPENSION	Ağırlık(kg) / Weight: 5.49
Çizim Ortamı / Drawing Env.: Solidworks 2016 Drawing			

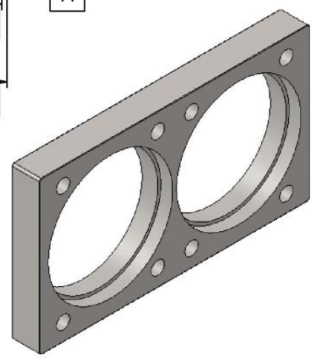
A4	Birim Unit: mm	İsim / Name	İmza / Signature	Tarih / Date
Ölçek Scale	Çizen / Drawn By	Can Kutay TUÇ		X
1:3	Kontrol / Checked	Can Kutay TUÇ		X
	Onay / Approval	Can Kutay TUÇ		X

Parça No / Part Or Ident No	001-01000-04-R00
Malzeme / Material	1.0044 (S275JR)
Parça Adı / Parts Name	PISTON CYLINDER
Sayfa Sheet	1/1



SECTION D-D
SCALE (1 : 3)





NOTES

1- 3D MODEL FILE WILL BE USED FOR THE DETAILS WHICH ARE NOT GIVEN IN DRAWING FILE.

2- 3D MODEL FILE WILL BE USED FOR THE DIMENSIONS WHICH ARE NOT GIVEN IN DRAWING FILE.
THE TOLERANCES GIVEN IN THE TOLERANCE TABLE ARE VALID FOR THE DIMENSIONS WHICH ARE TAKEN FROM 3D MODEL.

3- ZINC PLATING, BH-A-015, CLASS III, TYPE C.

4- SHARP EDGES WILL BE ROUNDED 0.5mm.

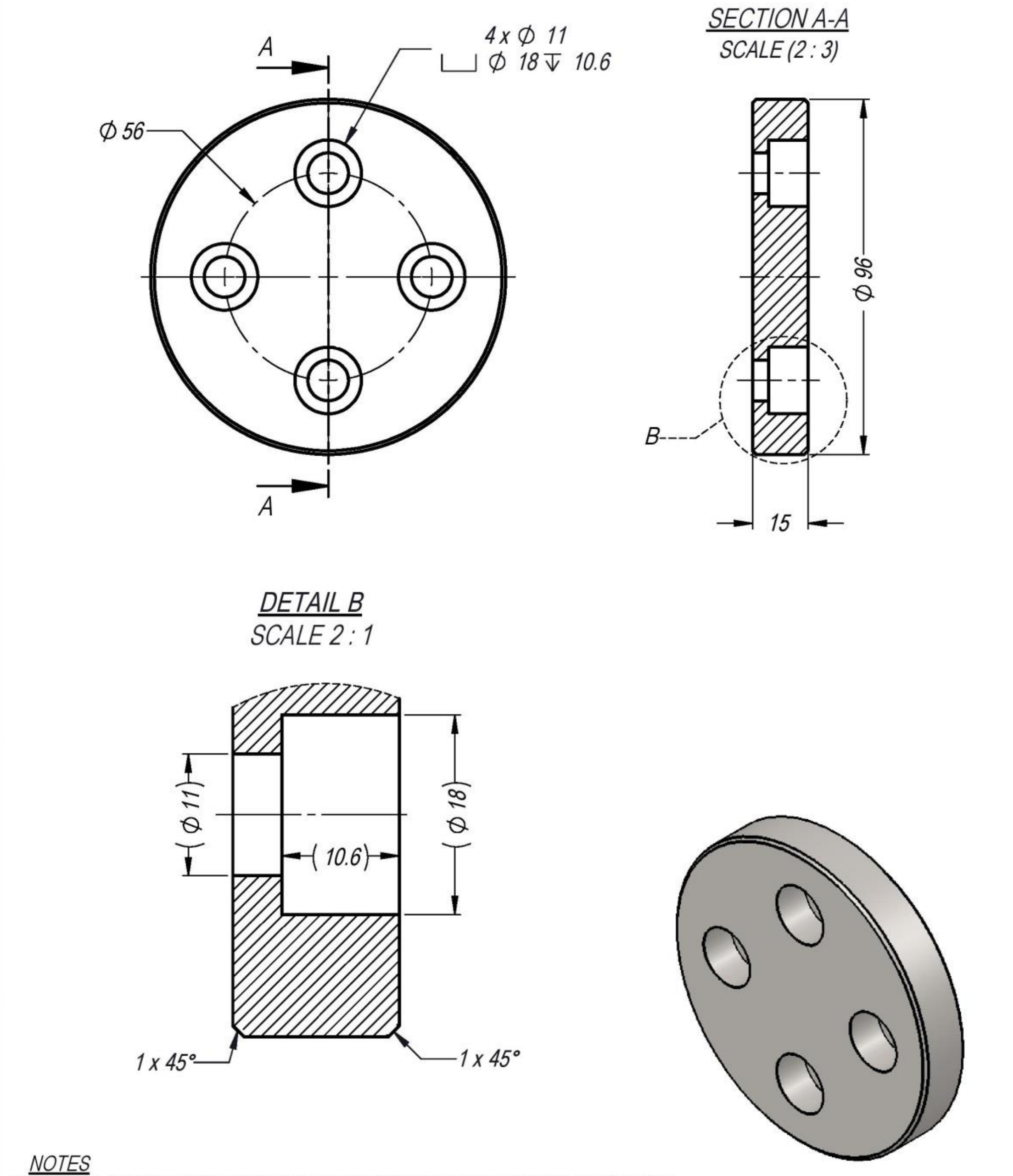
TS1980-1 EN22768-1

ÖLÇÜ ARALIĞI	>0.5 ≤6	>6 ≤30	>30 ≤120	>120 ≤400	>400 ≤1000	>1000 ≤2000	>2000 ≤4000
TOLERANS	±0.1	±0.2	±0.3	±0.5	±0.8	±1.2	±2

Genel Yüzey Pürüzlülüğü / General Roughness: 3.2 μm	Ait Olduğu Kompleler / Complete Numbers of Part	Proje Adı / Project Name: IN-ARM SUSPENSION	Ağırlık(kg) / Weight: 3.87	Çizim Ortamı / Drawing Env.: Solidworks 2016 Drawing

A4	Birim Unit: mm	İsim / Name	İmza / Signature	Tarih / Date
Ölçek Scale	Çizen / Drawn By	Can Kutay TUÇ		X
1:1	Kontrol / Checked	Can Kutay TUÇ		X
	Onay / Approval	Can Kutay TUÇ		X

Parça No / Part Or Ident No: 001-01000-05-R00	Malzeme / Material: 1.1191 (C45E)	
Parça Adı / Parts Name: HYDRAULIC BLOCK CAP		Sayfa Sheet: 1/1



NOTES

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2- 3D MODEL FILE WILL BE USED FOR THE DIMENSIONS WHICH ARE NOT GIVEN IN DRAWING FILE.
THE TOLERANCES GIVEN IN THE TOLERANCE TABLE ARE VALID FOR THE DIMENSIONS WHICH ARE TAKEN FROM 3D MODEL.

3- ZINC PLATING, BH-A-015, CLASS III, TYPE C.

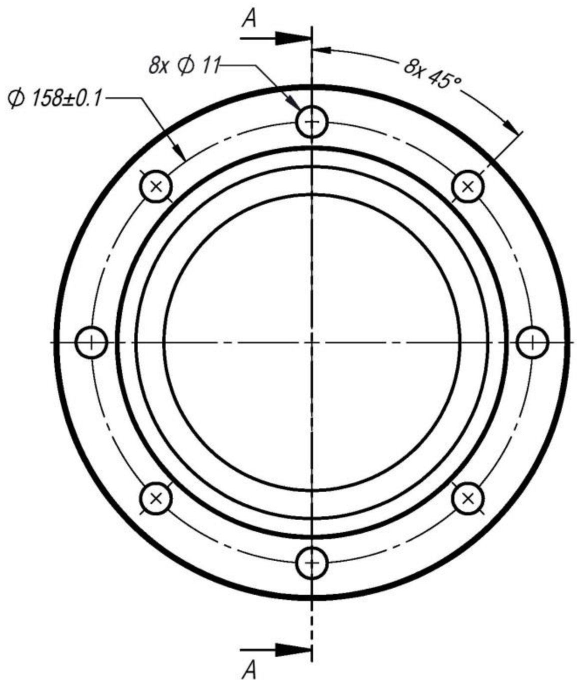
TS1980-1 EN22768-1

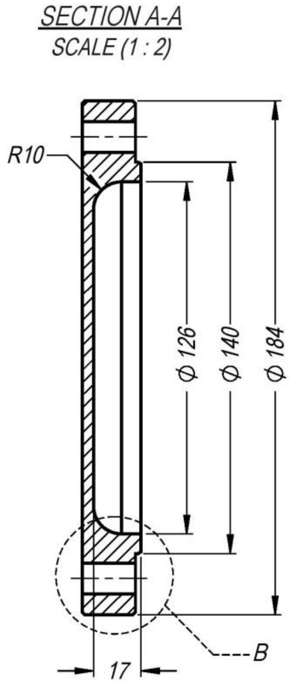
ÖLÇÜ ARALIĞI	>0.5 ≤6	>6 ≤30	>30 ≤120	>120 ≤400	>400 ≤1000	>1000 ≤2000	>2000 ≤4000
TOLERANS	±0.1	±0.2	±0.3	±0.5	±0.8	±1.2	±2

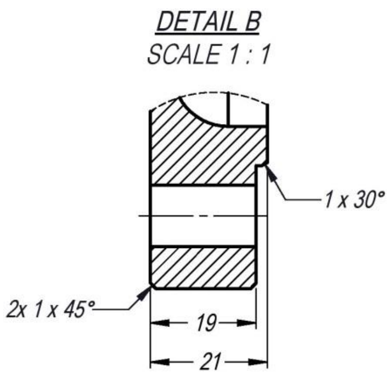
Genel Yüzey Pürüzlülüğü / General Roughness: 3.2 µm	Ait Olduğu Kompleler / Complete Numbers of Part	Proje Adı / Project Name: IN-ARM SUSPENSION	Ağırlık(kg) / Weight: 0.75	Çizim Ortamı / Drawing Env.: Solidworks 2016 Drawing
A4	Birim / Unit: mm			
Ölçek / Scale: 2:3				

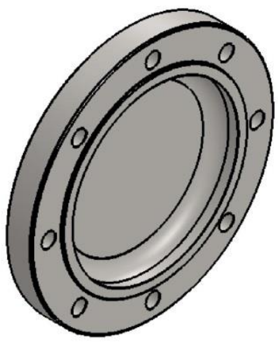
	İsim / Name	İmza / Signature	Tarih / Date
Çizen / Drawn By	Can Kutay TUÇ		X
Kontrol / Checked	Can Kutay TUÇ		X
Onay / Approval	Can Kutay TUÇ		X

Parça No / Part Or Ident No	001-01000-06-R00
Malzeme / Material	1.1191 (C45E)
Parça Adı / Parts Name	BEARING CAP
Sayfa / Sheet	1/1









NOTES

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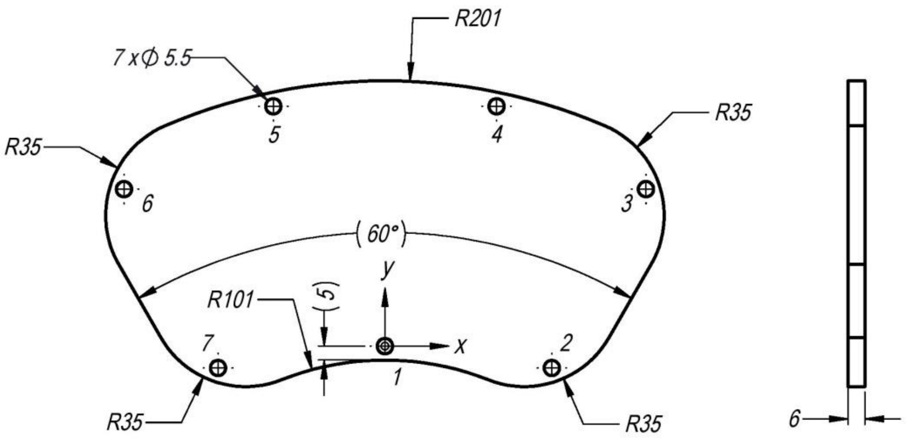
2- 3D MODEL FILE WILL BE USED FOR THE DIMENSIONS WHICH ARE NOT GIVEN IN DRAWING FILE.
THE TOLERANCES GIVEN IN THE TOLERANCE TABLE ARE VALID FOR THE DIMENSIONS WHICH ARE TAKEN FROM 3D MODEL.

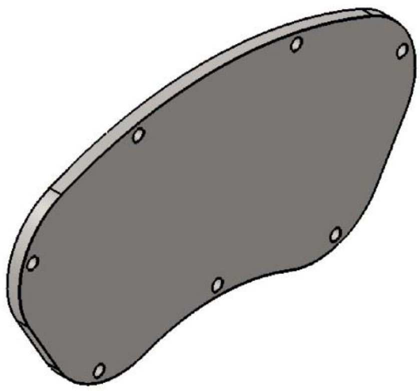
3- ZINC PLATING, BH-A-015, CLASS III, TYPE C.

TS1980-1 EN22768-1

ÖLÇÜ ARALIĞI	>0.5 ≤6	>6 ≤30	>30 ≤120	>120 ≤400	>400 ≤1000	>1000 ≤2000	>2000 ≤4000
TOLERANS	±0.1	±0.2	±0.3	±0.5	±0.8	±1.2	±2

Genel Yüzey Pürüzlülüğü / General Roughness	3.2 μm	Ait Olduğu Kompleler / Complete Numbers of Part		
Proje Adı / Project Name	IN-ARM SUSPENSION	Ağırlık(kg) / Weight	2.47	Çizim Ortamı / Drawing Env.: Solidworks 2016 Drawing
A4	Birim / Unit: mm	İsim / Name	İmza / Signature	Tarih / Date
Ölçek / Scale: 2:3	Çizen / Drawn By	Can Kutay TUÇ		X
	Kontrol / Checked	Can Kutay TUÇ		X
	Onay / Approval	Can Kutay TUÇ		X
Parça No / Part Or Ident No	001-01000-07-R00	Malzeme / Material	1.1191 (C45E)	
Parça Adı / Parts Name	REAR CAP	Sayfa / Sheet	1/1	





REF NO	X AXIS LOCATION	Y AXIS LOCATION
1	0,00	0,00
2	59,82	-7,83
3	93,53	56,21
4	40,00	85,87
5	-40	85,87
6	-93,53	56,21
7	-59,82	-7,83

NOTES

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2- 3D MODEL FILE WILL BE USED FOR THE DIMENSIONS WHICH ARE NOT GIVEN IN DRAWING FILE.
THE TOLERANCES GIVEN IN THE TOLERANCE TABLE ARE VALID FOR THE DIMENSIONS WHICH ARE TAKEN FROM 3D MODEL.

3- ZINC PLATING, BH-A-015, CLASS III, TYPE C.

TS1980-1 EN22768-1

ÖLÇÜ ARALIĞI	>0.5 ≤6	>6 ≤30	>30 ≤120	>120 ≤400	>400 ≤1000	>1000 ≤2000	>2000 ≤4000
TOLERANS	±0.1	±0.2	±0.3	±0.5	±0.8	±1.2	±2

Genel Yüzey Pürüzlülüğü / General Roughness: 3.2 μm

Ait Olduğu Kompleler / Complete Numbers of Part:

Proje Adı / Project Name: IN-ARM SUSPENSION

Ağırlık(kg) / Weight: 0.82

Çizim Ortamı / Drawing Env.: Solidworks 2016 Drawing

A4 — Birim Unit: mm

	İsim / Name	İmza / Signature	Tarih / Date
Çizen / Drawn By	Can Kutay TUÇ		X
Kontrol / Checked	Can Kutay TUÇ		X
Onay / Approval	Can Kutay TUÇ		X

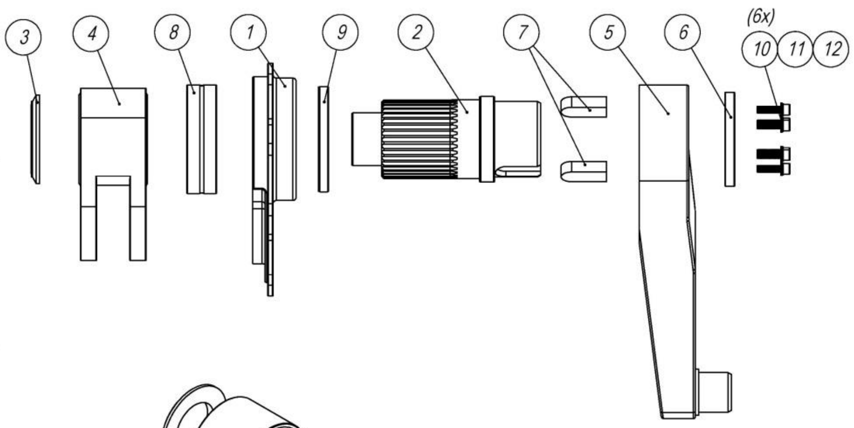
Ölçek Scale: 2:3

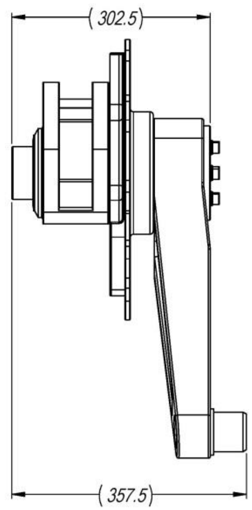
Parça No / Part Or Ident No: 001-01000-08-R00

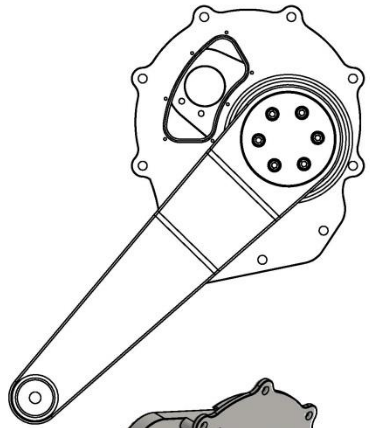
Malzeme / Material: 1.0037 (S235JR)

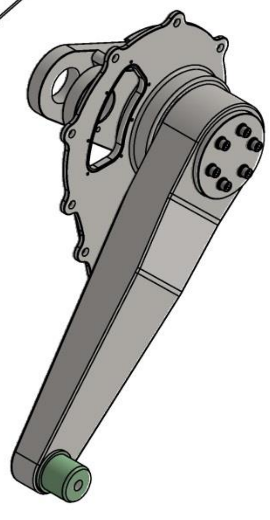
Parça Adı / Parts Name: MAINTENANCE CAP

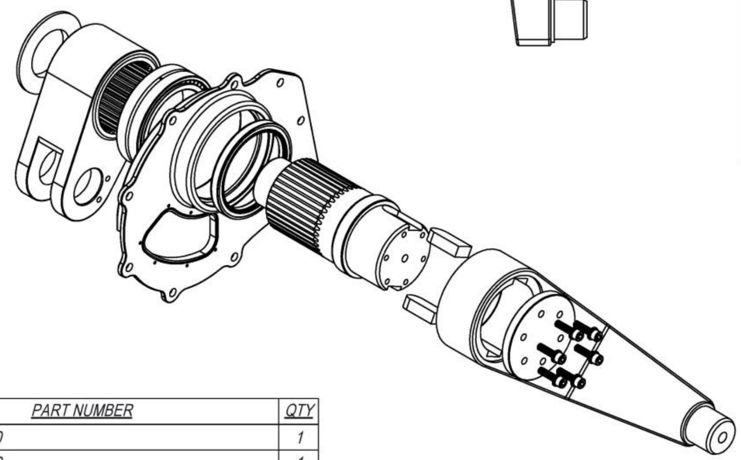
Sayfa Sheet: 1/1







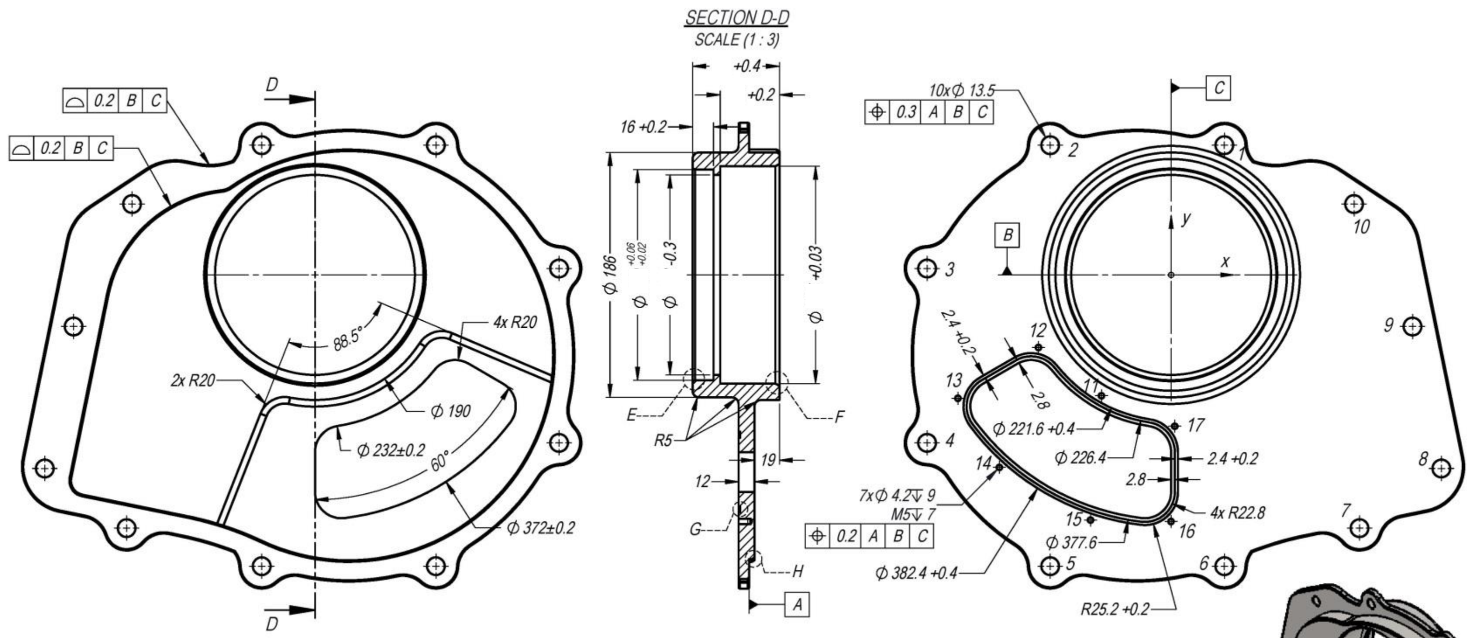


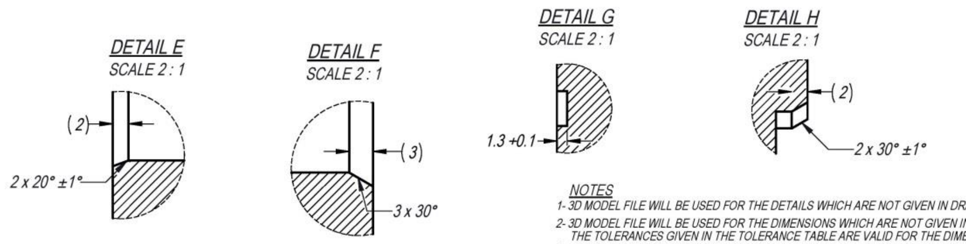


NO	PART NUMBER	QTY
1	001-01100-01-R00	1
2	001-01100-02-R00	1
3	001-01100-03-R00	1
4	001-01100-04-R00	1
5	001-01100-05-R00	1
6	001-01100-06-R00	1
7	001-01100-07-R00	2
8	BEARING_NNCF_4924_CV	1
9	ROTARY_SEAL_130x160x15	1
10	WASHER_DIN125_M10	6
11	SPRING_WASHER_DIN128_M10	6
12	BOLT_DIN912_M10x40	6

	Genel Yüzey Pürüzlülüğü / General Roughness: - µm	Ait Olduğu Kompleler / Complete Numbers of Part			Proje Adı / Project Name: IN-ARM SUSPENSION
A3	Birim / Unit: mm	İsim / Name	İmza / Signature	Tarih / Date	Parça No / Part Or Ident No: 001-01100-00-R00
Ölçek / Scale	Çizen / Drawn By	Can Kutay TUÇ		x	
1:1	Kontrol / Checked	Can Kutay TUÇ		x	Parça Adı / Parts Name: SUSPENSION ARM ASSEMBLY
	Onay / Approval	Can Kutay TUÇ		x	

Ağırlık(kg) / Weight	79.20
Çizim Ortamı / Drawing Env.	Solidworks 2016 Drawing
Malzeme / Material	ASSEMBLY
Sayfa / Sheet	1/1





REF NO	X AXIS LOCATION	Y AXIS LOCATION
1	40.48	98.48
2	-91.93	98.48
3	-185.56	4.85
4	-185.56	-127.56
5	-91.93	-221.19
6	40.48	-221.19
7	143.22	-192.31
8	205.43	-146.99
9	183.50	-39.20
10	139.06	53.81
11	-53.00	-91.80
12	-100.89	-55.11
13	-162.11	-93.71
14	-130.58	-146.17
15	-61.30	-186.17
16	-0.11	-187.25
17	2.72	-114.93

NOTES

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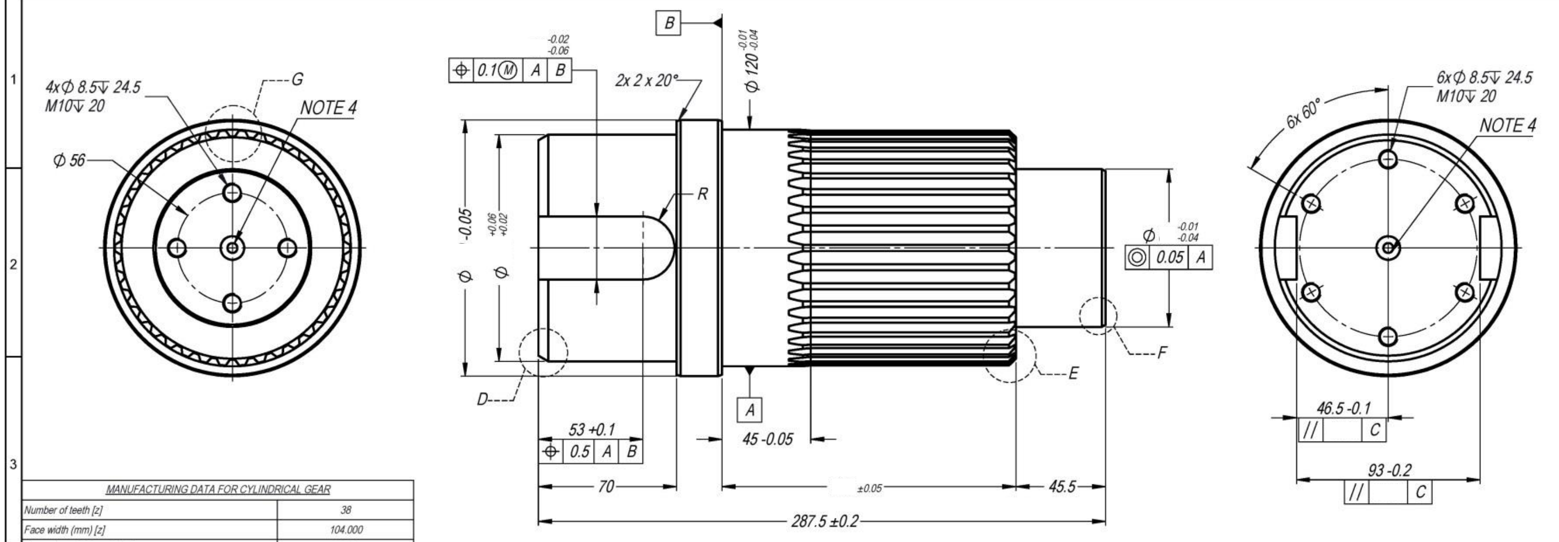
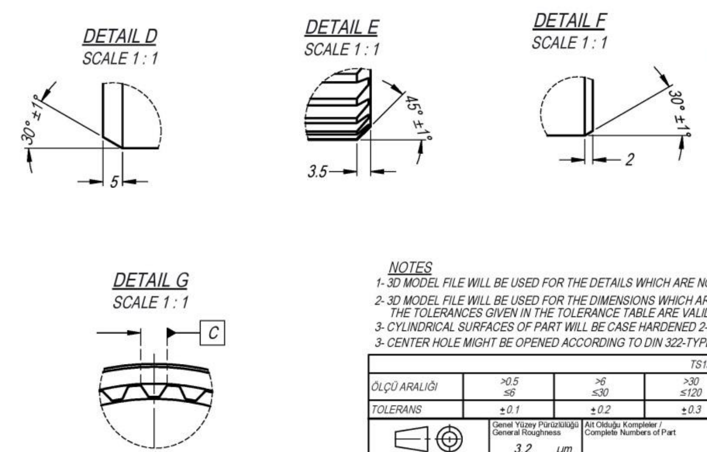
2- 3D MODEL FILE WILL BE USED FOR THE DIMENSIONS WHICH ARE NOT GIVEN IN DRAWING FILE.
THE TOLERANCES GIVEN IN THE TOLERANCE TABLE ARE VALID FOR THE DIMENSIONS WHICH ARE TAKEN FROM 3D MODEL.
3- ZINC PLATING, BH-A-015, CLASS III, TYPE C.
4- SHARP EDGES WILL BE ROUNDED 1mm.

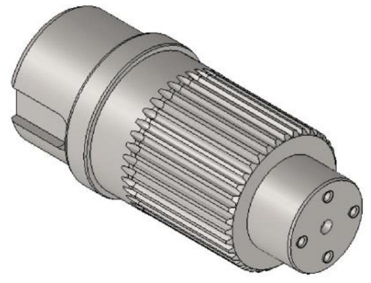
TS1980-1 EN22768-1

ÖLÇÜ ARALIĞI	>0.5 ≤6	>6 ≤30	>30 ≤120	>120 ≤400	>400 ≤1000	>1000 ≤2000	>2000 ≤4000
TOLERANS	±0.1	±0.2	±0.3	±0.5	±0.8	±1.2	±2

Genel Yüzey Pürüzlülüğü / General Roughness: 3.2 µm	Ait Olduğu Kompleler / Complete Numbers of Part		Proje Adı / Project Name: IN-ARM SUSPENSION	Ağırlık(kg) / Weight: 14.54	Çizim Ortamı / Drawing Env.: Solidworks 2016 Drawing
A3	Birim / Unit: mm		Parça No / Part Or Ident No: 001-01100-01-R00	Malzeme / Material: 1.1191 (C45E)	
Ölçek / Scale: 1:3	İsim / Name	İmza / Signature	Tarih / Date		
Çizen / Drawn By	Can Kutay TUÇ		x	Parça Adı / Parts Name: FRONT COVER	Sayfa / Sheet: 1/1
Kontrol / Checked	Can Kutay TUÇ		x		
Onay / Approval	Can Kutay TUÇ		x		







MANUFACTURING DATA FOR CYLINDRICAL GEAR	
Number of teeth [z]	38
Face width (mm) [z]	104.000
Normal module (mm) [mn]	
Helix angle (°) [beta]	0.000
Hand of gear	Spur gear
Pressure angle at normal section (°) [alfn]	30.000
Reference profile	DIN 5480:2006 0.55 / 0.16 / 0.45
Addendum coefficient [haP]	0.450
Dedendum coefficient [hfP]	0.550
Tip radius factor [rhoaP]	0.000
Root radius factor [rhofP]	0.160
Tip form height coefficient [hFaP]	0.000
Protuberance height factor [hprP]	0.000
Protuberance angle (°) [alfprP]	0.000
Ramp angle (°) [alfKP]	0.000
Accuracy grade according DIN 3961	8
Profile shift coefficient [x]	
Reference diameter (mm) [d]	
Tip diameter (mm) [da]	(0.000 / -0.220)
Root diameter (mm) [df]	(-0.040 / -0.109)
Tooth thickness deviation	DIN 5480 h
Tooth thickness allowance (normal section) (mm) [As.e/i]	0.000 / -0.023
Number of teeth spanned [k]	7
Base tangent length (no backlash)(mm) [Wk]	59.710
Actual base tangent length ('span') (mm) [Wk.e/i]	59.710 / 59.690
Effective diameter of ball/pin (mm) [DMeff]	6.000
Measurement over pins according to DIN 3960 (mm) [MdR.e/i]	126.095 / 126.060
Measurement over 3 pins (AGMA 2002) (mm) [MdR.e/i]	126.095 / 126.060
Chordal tooth thickness (without backlash) (mm) [sc]	6.268
Actual chordal tooth thickness (mm) [sc.e/i]	6.268 / 6.245
Reference chordal height (mm) [ha]	2.731

NOTES

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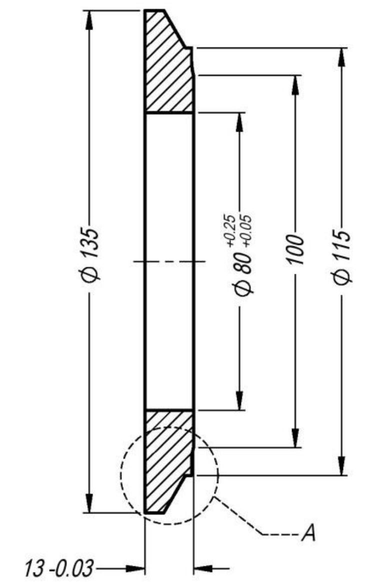
2- 3D MODEL FILE WILL BE USED FOR THE DIMENSIONS WHICH ARE NOT GIVEN IN DRAWING FILE.
THE TOLERANCES GIVEN IN THE TOLERANCE TABLE ARE VALID FOR THE DIMENSIONS WHICH ARE TAKEN FROM 3D MODEL.
3- CYLINDRICAL SURFACES OF PART WILL BE CASE HARDENED 2-3mm THICKNESS, 55-60HRC HARDNESS.
3- CENTER HOLE MIGHT BE OPENED ACCORDING TO DIN 322-TYPEB (5mm).

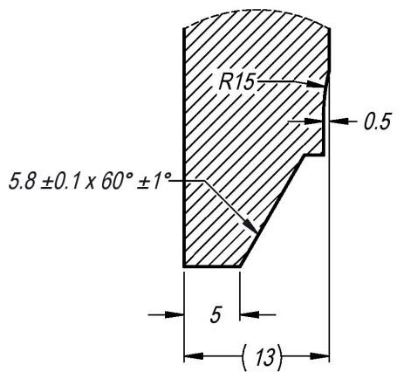
TS1980-1 EN22768-1							
ÖLÇÜ ARALIĞI	>0.5 ≤6	>6 ≤30	>30 ≤120	>120 ≤400	>400 ≤1000	>1000 ≤2000	>2000 ≤4000
TOLERANS	±0.1	±0.2	±0.3	±0.5	±0.8	±1.2	±2

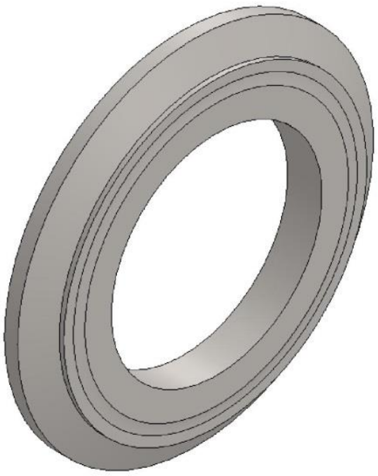
Genel Yüzey Pürüzlülüğü / General Roughness: 3.2 μm	Ait Olduğu Kompleler / Complete Numbers of Part	Proje Adı / Project Name: IN-ARM SUSPENSION	Ağırlık(kg) / Weight: 21.93	Çizim Ortamı / Drawing Env.: Solidworks 2016 Drawing	
A3	Birim / Unit: mm	Parça No / Part Or Ident No: 001-01100-02-R00	Malzeme / Material: 1.6587 (18CrNiMo7-6)		
Ölçek / Scale: 1:2		İsim / Name	İmza / Signature	Tarih / Date	
	Çizen / Drawn By	Can Kutay TUÇ		x	
	Kontrol / Checked	Can Kutay TUÇ		x	Parça Adı / Parts Name: ARM SHAFT
	Onay / Approval	Can Kutay TUÇ		x	Sayfa / Sheet: 1/1

A	B	C	D



DETAIL A
SCALE 2 : 1





NOTES
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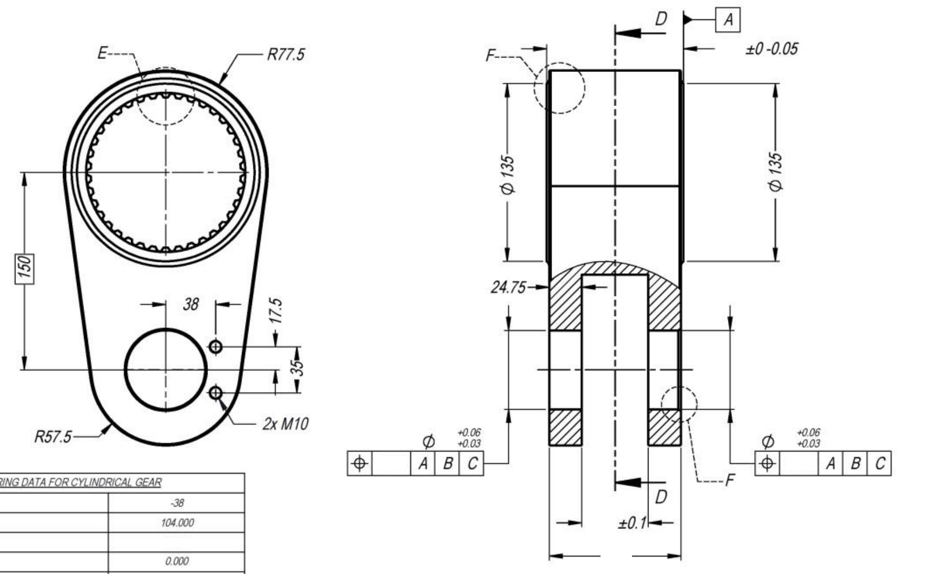
2- 3D MODEL FILE WILL BE USED FOR THE DIMENSIONS WHICH ARE NOT GIVEN IN DRAWING FILE.
THE TOLERANCES GIVEN IN THE TOLERANCE TABLE ARE VALID FOR THE DIMENSIONS WHICH ARE TAKEN FROM 3D MODEL.
3- ZINC PLATING, BH-A-015, CLASS III, TYPE C.

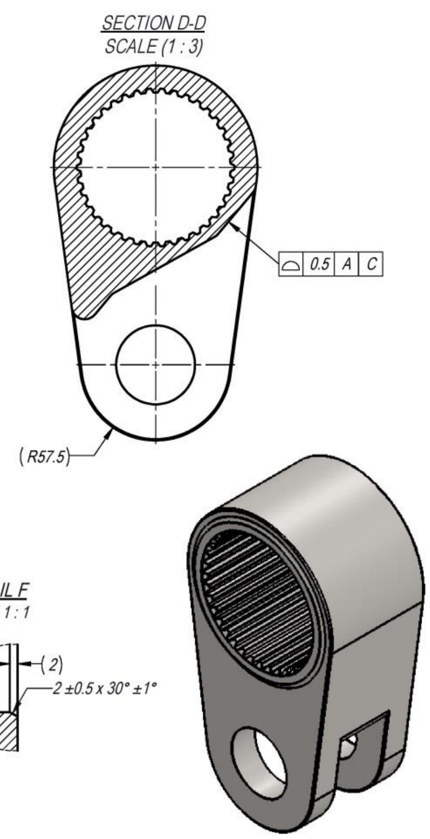
TS1980-1 EN22768-1

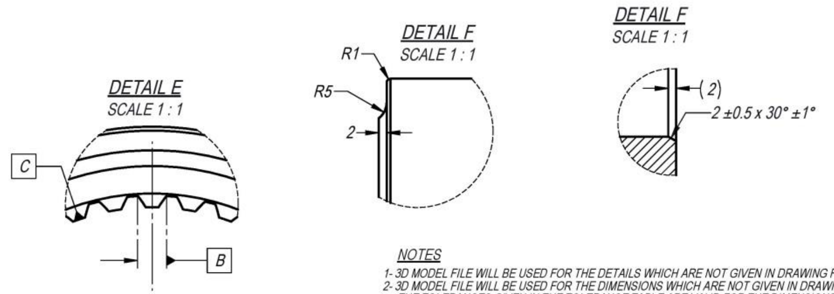
ÖLÇÜ ARALIĞI	>0.5 ≤6	>6 ≤30	>30 ≤120	>120 ≤400	>400 ≤1000	>1000 ≤2000	>2000 ≤4000
TOLERANS	±0.1	±0.2	±0.3	±0.5	±0.8	±1.2	±2

Genel Yüzey Pürüzlülüğü / General Roughness: 3.2 μm	Ait Olduğu Kompleler / Complete Numbers of Part	Proje Adı / Project Name: IN-ARM SUSPENSION	Ağırlık(kg) / Weight: 0.77	Çizim Ortamı / Drawing Env.: Solidworks 2016 Drawing

A4	Birim Unit mm	İsim / Name	İmza / Signature	Tarih / Date	Parça No / Part Or Ident No	Malzeme / Material
Ölçek Scale	Çizen / Drawn By	Can Kutay TUÇ		X	001-01100-03-R00	1.1191 (C45E)
2:3	Kontrol / Checked	Can Kutay TUÇ		X	Parça Adı / Parts Name: LOCATING SHIM	Sayfa Sheet 1/1
	Onay / Approval	Can Kutay TUÇ		X		







MANUFACTURING DATA FOR CYLINDRICAL GEAR	
Number of teeth [z]	-38
Face width (mm) [z]	104.000
Normal module (mm) [mn]	
Helix angle (°) [beta]	0.000
Hand of gear	Spur gear
Pressure angle at normal section (°) [alfn]	30.000
Reference profile	DIN 5480:2006 0.55 / 0.16 / 0.45
Addendum coefficient [haP]	0.450
Dedendum coefficient [hfP]	0.550
Tip radius factor [rhoaP]	0.000
Root radius factor [rhofP]	0.160
Tip form height coefficient [hFaP]	0.000
Protuberance height factor [hprP]	0.000
Protuberance angle (°) [alfprP]	0.000
Ramp angle (°) [alfKP]	0.000
Accuracy grade according DIN 3961	9
Profile shift coefficient [x]	
Reference diameter (mm) [d]	
Tip diameter (mm) [da]	(0.000 / 0.220)
Root diameter (mm) [df]	(0.059 / 0.156)
Tooth thickness deviation	DIN 5480 H
Tooth thickness allowance (normal section) (mm) [As.e/i]	0.000 / -0.034
Number of teeth spanned [k]	-7
Base tangent length (no backlash)(mm) [Wk]	-59.710
Actual base tangent length ('span') (mm) [Wk.e/i]	-59.710 / -59.740
Effective diameter of ball/pin (mm) [DMeff]	5.500
Measurement over pins according to DIN 3960 (mm) [MdR.e/i]	108.362 / 108.421
Measurement over 3 pins (AGMA 2002) (mm) [MdR.e/i]	108.362 / 108.421
Chordal tooth thickness (without backlash) (mm) [sc]	3.153
Actual chordal tooth thickness (mm) [sc.e/i]	3.153 / 3.119
Reference chordal height (mm) [ha]	-0.077

NOTES

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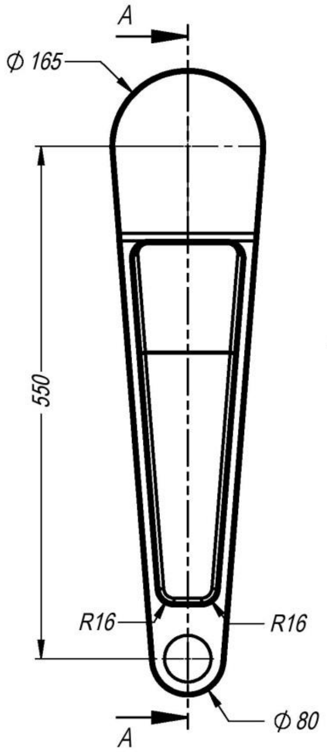
2- 3D MODEL FILE WILL BE USED FOR THE DIMENSIONS WHICH ARE NOT GIVEN IN DRAWING FILE.
THE TOLERANCES GIVEN IN THE TOLERANCE TABLE ARE VALID FOR THE DIMENSIONS WHICH ARE TAKEN FROM 3D MODEL.
3- TEETH WILL BE CASE HARDENED 2-3mm THICKNESS, 55-60HRC HARDNESS.
4- SHARP EDGES WILL BE ROUNDED 1mm.

TS1980-1 EN22768-1							
ÖLÇÜ ARALIĞI	>0.5 ≤6	>6 ≤30	>30 ≤120	>120 ≤400	>400 ≤1000	>1000 ≤2000	>2000 ≤4000
TOLERANS	±0.1	±0.2	±0.3	±0.5	±0.8	±1.2	±2

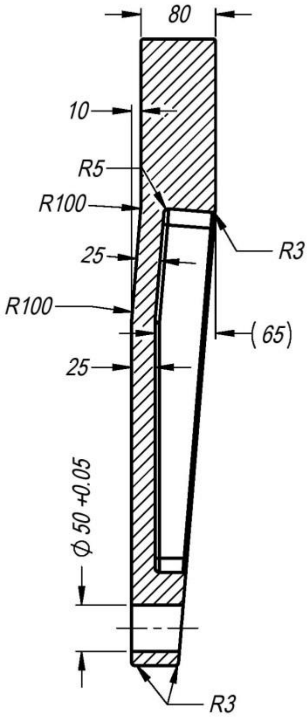
	Genel Yüzey Pürüzlülüğü / General Roughness 3.2 μm	Ait Olduğu Kompleler / Complete Numbers of Part		Proje Adı / Project Name: IN-ARM SUSPENSION	Ağırlık(kg) / Weight: 12.22	Çizim Ortamı / Drawing Env.: Solidworks 2016 Drawing
A3 — Birim / Unit: mm	İsim / Name	İmza / Signature	Tarih / Date	Parça No / Part Or Ident No: 001-01100-04-R00	Malzeme / Material: 1.6587 (18CrNiMo7-6)	
Ölçek / Scale: 1:3 — Çizen / Drawn By	Can Kutay TUÇ		x	Parça Adı / Parts Name: SUSPENSION ARM		Sayfa / Sheet: 1/1
Kontrol / Checked	Can Kutay TUÇ		x			
Onay / Approval	Can Kutay TUÇ		x			

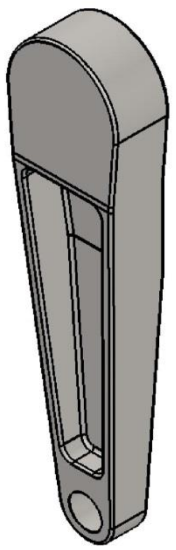
A	B	C	D

001-01100-05-R00-01
SCALE 1:6

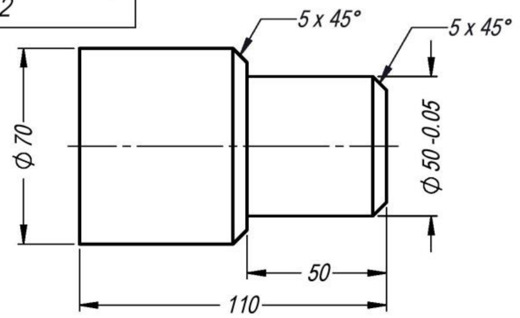


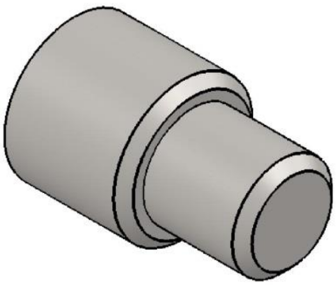
SECTION A-A
SCALE (1 : 6)





001-01100-05-R00-02
SCALE 1:2





NOTES
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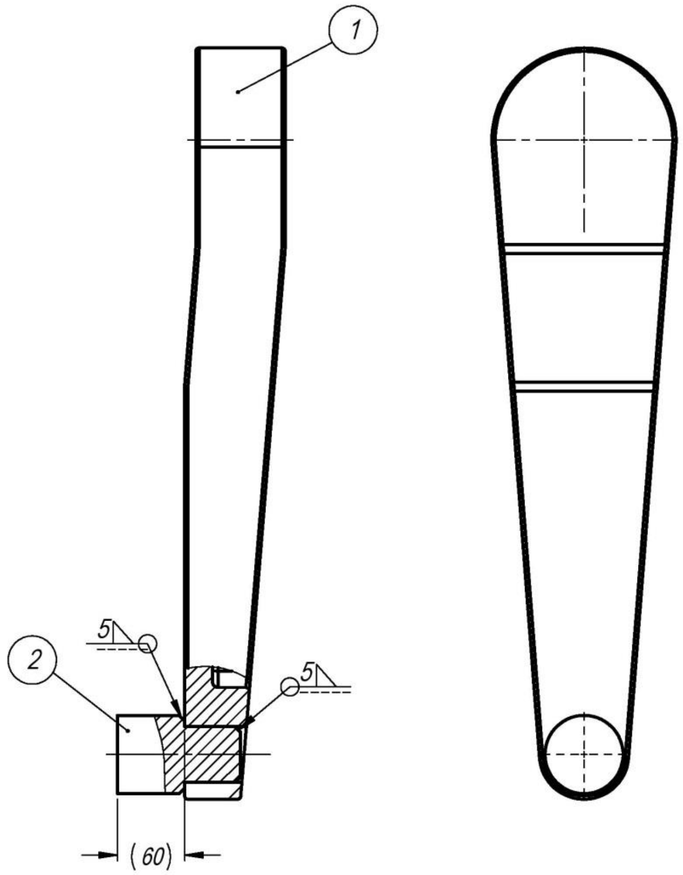
2- 3D MODEL FILE WILL BE USED FOR THE DIMENSIONS WHICH ARE NOT GIVEN IN DRAWING FILE.
THE TOLERANCES GIVEN IN THE TOLERANCE TABLE ARE VALID FOR THE DIMENSIONS WHICH ARE TAKEN FROM 3D MODEL.

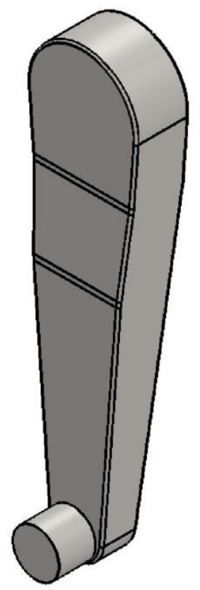
TS1980-1 EN22768-1

ÖLÇÜ ARALIĞI	>0.5 ≤6	>6 ≤30	>30 ≤120	>120 ≤400	>400 ≤1000	>1000 ≤2000	>2000 ≤4000
TOLERANS	±0.1	±0.2	±0.3	±0.5	±0.8	±1.2	±2

	Genel Yüzey Pürüzlülüğü / General Roughness: 3.2 μm	Ait Olduğu Kompleler / Complete Numbers of Part	Proje Adı / Project Name: IN-ARM SUSPENSION		Ağırlık(kg) / Weight: 35.07	Çizim Ortamı / Drawing Env.: Solidworks 2016 Drawing
A4	Birim Unit: mm	İsim / Name	İmza / Signature	Tarih / Date	Parça No / Part Or Ident No: 001-01100-05-R00	Malzeme / Material: 1.0570 (S355J2G3)
Ölçek Scale: 2:3	Çizen / Drawn By	Can Kutay TUÇ		X		
	Kontrol / Checked	Can Kutay TUÇ		X	Parça Adı / Parts Name: WHEEL ARM	Sayfa Sheet: 1/1
	Onay / Approval	Can Kutay TUÇ		X		

	A	B	C	D





NO	PART NUMBER	PART NAME	MASS	QTY
1	001-01100-05-R00-01	WHEEL ARM BODY	32.54	1
2	001-01100-05-R00-02	WHEEL ARM PIN	2.53	1

NOTES

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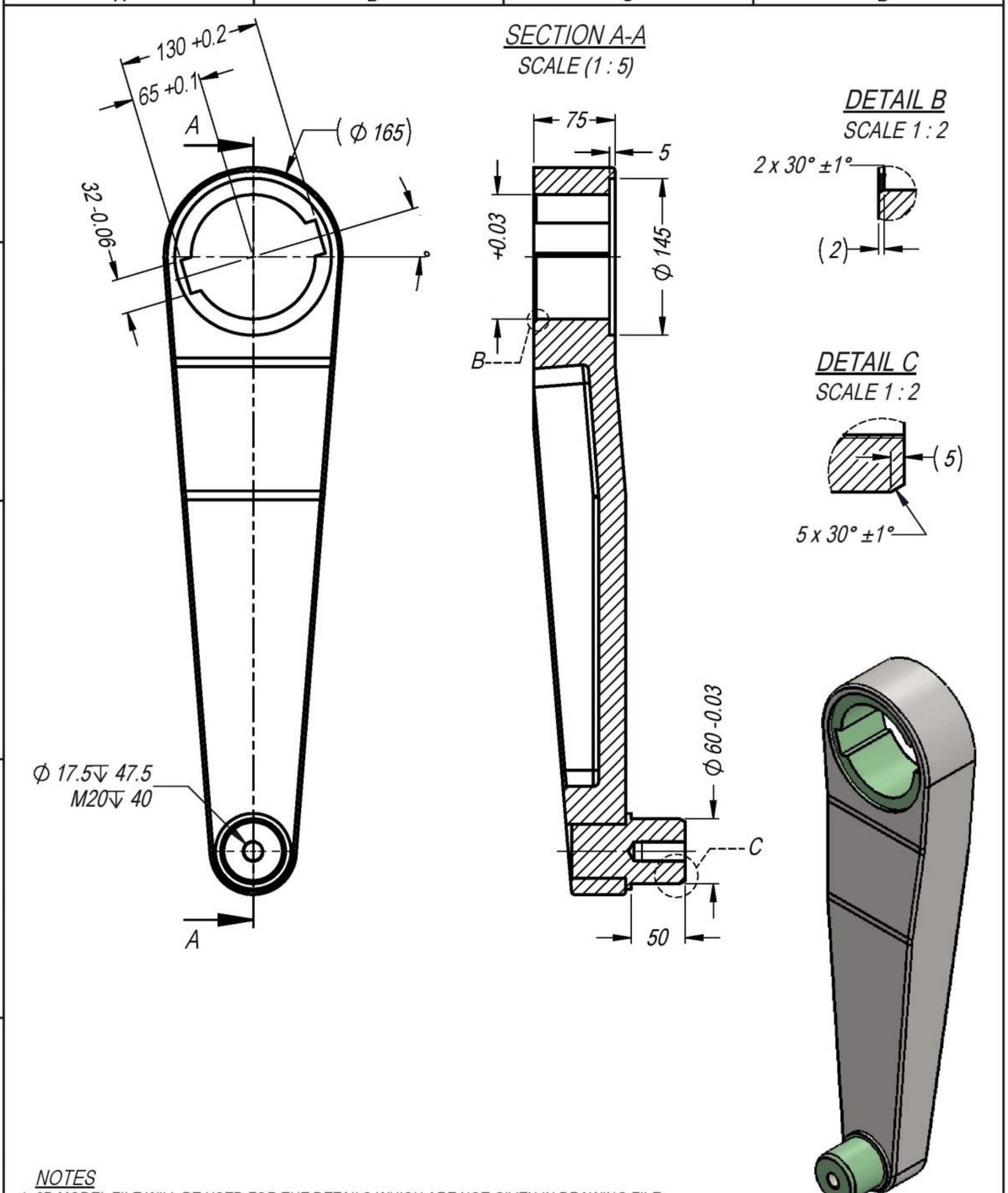
TS1980-1 EN22768-1

ÖLÇÜ ARALIĞI	>0.5 ≤6	>6 ≤30	>30 ≤120	>120 ≤400	>400 ≤1000	>1000 ≤2000	>2000 ≤4000
TOLERANS	±0.1	±0.2	±0.3	±0.5	±0.8	±1.2	±2

Genel Yüzey Pürüzlülüğü / General Roughness: - μm	Ait Olduğu Kompleler / Complete Numbers of Part	Proje Adı / Project Name: IN-ARM SUSPENSION	Ağırlık(kg) / Weight: 35.07	Çizim Ortamı / Drawing Env.: Solidworks 2016 Drawing	
A4	Birim Unit: mm	İsim / Name	İmza / Signature	Tarih / Date	Parça No / Part Or Ident No: 001-01100-05-R00
Ölçek Scale: 2:3	Çizen / Drawn By	Can Kutay TUÇ		X	Malzeme / Material: 1.0570 (S355J2G3)
	Kontrol / Checked	Can Kutay TUÇ		X	Parça Adı / Parts Name: WHEEL ARM
	Onay / Approval	Can Kutay TUÇ		X	Sayfa Sheet: 1/1



NOTES

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2- 3D MODEL FILE WILL BE USED FOR THE DIMENSIONS WHICH ARE NOT GIVEN IN DRAWING FILE. THE TOLERANCES GIVEN IN THE TOLERANCE TABLE ARE VALID FOR THE DIMENSIONS WHICH ARE TAKEN FROM 3D MODEL.

3- ZINC PLATING, BH-A-015, CLASS III, TYPE C.

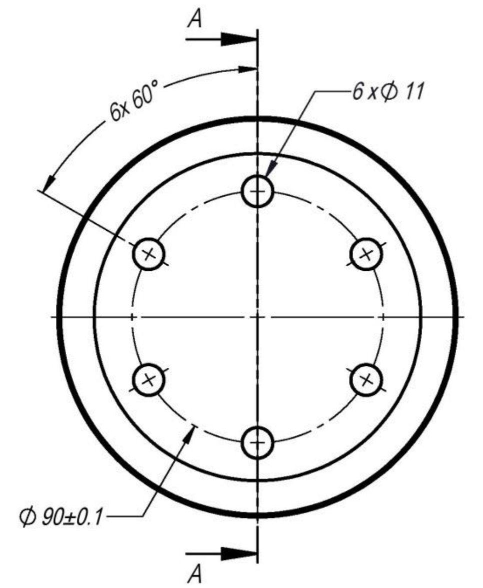
TS1980-1 EN22768-1

ÖLÇÜ ARALIĞI	>0.5 ≤6	>6 ≤30	>30 ≤120	>120 ≤400	>400 ≤1000	>1000 ≤2000	>2000 ≤4000
TOLERANS	±0.1	±0.2	±0.3	±0.5	±0.8	±1.2	±2

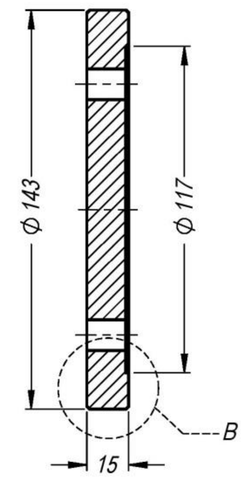
Genel Yüzey Pürüzlülüğü / General Roughness: 3.2 µm	Ait Olduğu Kompleler / Complete Numbers of Part	Proje Adı / Project Name: IN-ARM SUSPENSION	Ağırlık(kg) / Weight: 35.07	Çizim Ortamı / Drawing Env.: Solidworks 2016 Drawing
A4	Birim Unit: mm	Parça No / Part Or Ident No: 001-01100-05-R00	Malzeme / Material: 1.0570 (S355J2G3)	
Ölçek Scale: 1:5		Parça Adı / Parts Name: WHEEL ARM	Sayfa Sheet: 1/1	

	İsim / Name	İmza / Signature	Tarih / Date
Çizen / Drawn By	Can Kutay TUÇ		X
Kontrol / Checked	Can Kutay TUÇ		X
Onay / Approval	Can Kutay TUÇ		X

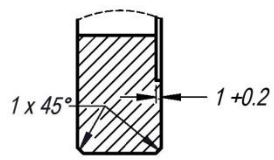
A	B	C	D

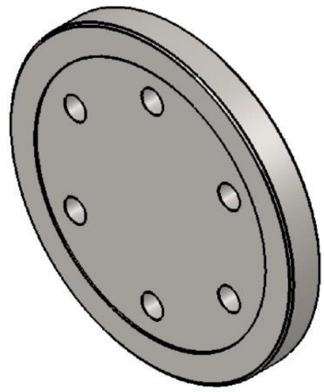


SECTION A-A



DETAIL B
SCALE 1 : 1





NOTES

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3- ZINC PLATING, BH-A-015, CLASS III, TYPE C.

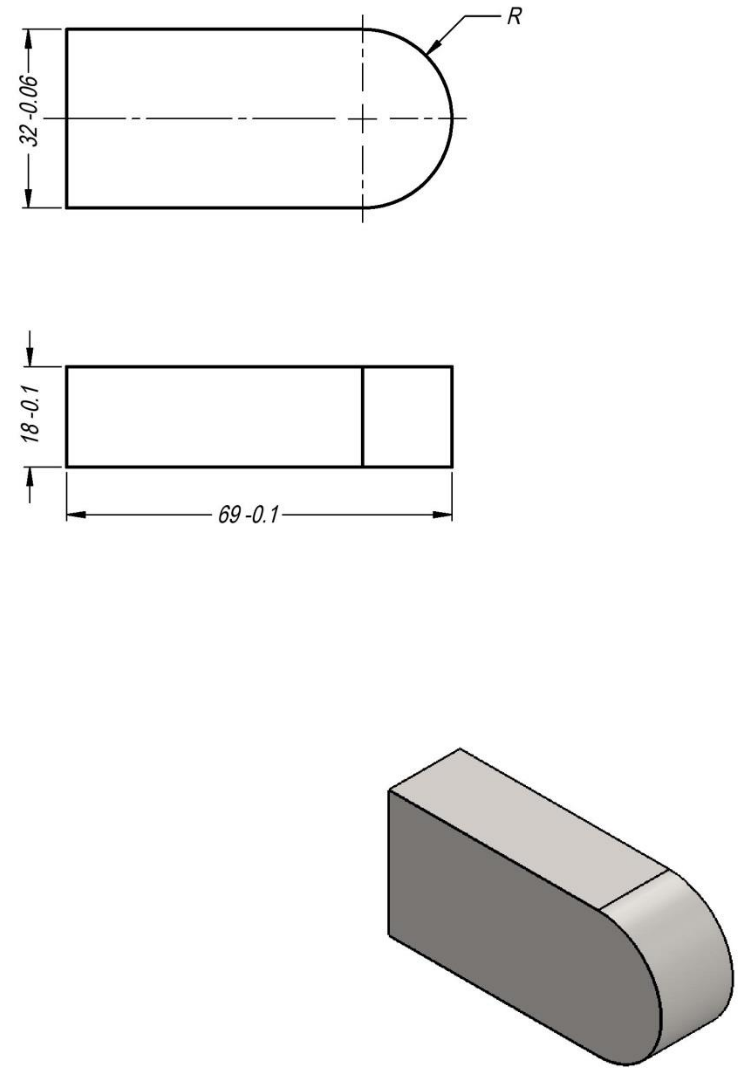
TS1980-1 EN22768-1

ÖLÇÜ ARALIĞI	>0.5 ≤6	>6 ≤30	>30 ≤120	>120 ≤400	>400 ≤1000	>1000 ≤2000	>2000 ≤4000
TOLERANS	±0.1	±0.2	±0.3	±0.5	±0.8	±1.2	±2

Genel Yüzey Pürüzlülüğü / General Roughness: 3.2 μm	Ait Olduğu Kompleler / Complete Numbers of Part	Proje Adı / Project Name: IN-ARM SUSPENSION	Ağırlık(kg) / Weight: 1.73
Çizim Ortamı / Drawing Env.: Solidworks 2016 Drawing			

A4	Birim Unit: mm	İsim / Name	İmza / Signature	Tarih / Date
Ölçek Scale	Çizen / Drawn By	Can Kutay TUÇ		X
1:2	Kontrol / Checked	Can Kutay TUÇ		X
	Onay / Approval	Can Kutay TUÇ		X

Parça No / Part Or Ident No	001-01100-06-R00
Malzeme / Material	1.1191 (C45E)
Parça Adı / Parts Name	WHEEL ARM CAP
Sayfa Sheet	1/1



NOTES

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3- ZINC PLATING, BH-A-015, CLASS III, TYPE C.

TS1980-1 EN22768-1

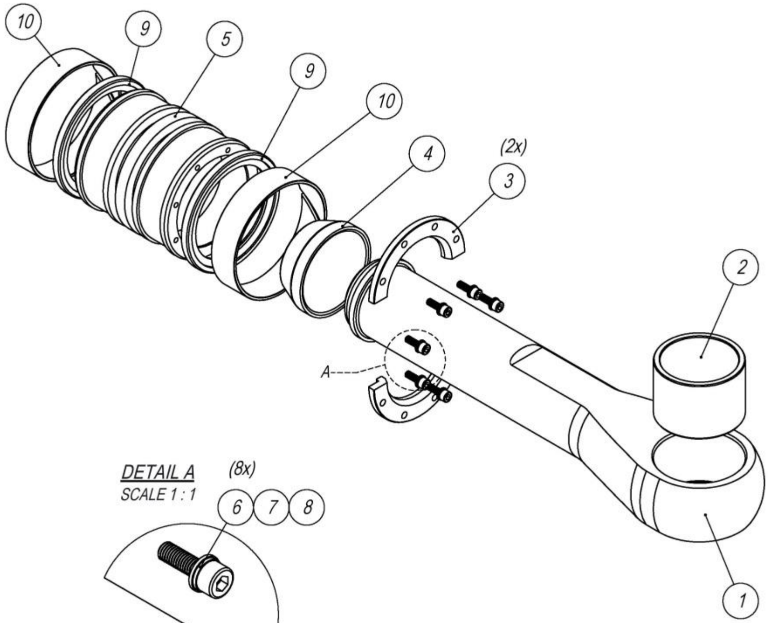
ÖLÇÜ ARALIĞI	>0.5 ≤6	>6 ≤30	>30 ≤120	>120 ≤400	>400 ≤1000	>1000 ≤2000	>2000 ≤4000
TOLERANS	±0.1	±0.2	±0.3	±0.5	±0.8	±1.2	±2

Genel Yüzey Pürüzlülüğü / General Roughness: 3.2 µm	Ait Olduğu Kompleler / Complete Numbers of Part	Proje Adı / Project Name: IN-ARM SUSPENSION	Ağırlık(kg) / Weight: 0.29	Çizim Ortamı / Drawing Env.: Solidworks 2016 Drawing	
A4	Birim Unit: mm	Parça No / Part Or Ident No: 001-01100-07-R00	Malzeme / Material: 1.1191 (C45E)		

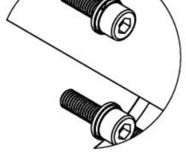
Ölçek Scale		İsim / Name	İmza / Signature	Tarih / Date
1:1	Çizen / Drawn By	Can Kutay TUÇ		X
	Kontrol / Checked	Can Kutay TUÇ		X
	Onay / Approval	Can Kutay TUÇ		X

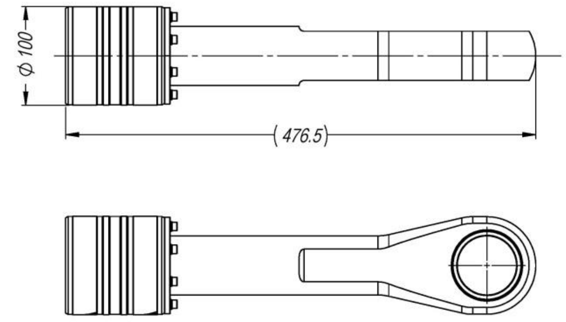
Parça Adı / Parts Name: WHEEL ARM KEY

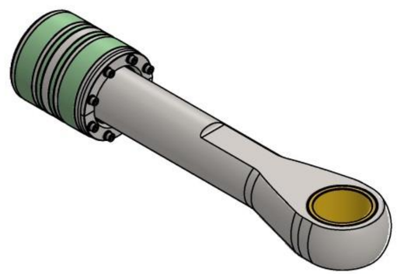
Sayfa Sheet: 1/1



DETAIL A
SCALE 1 : 1

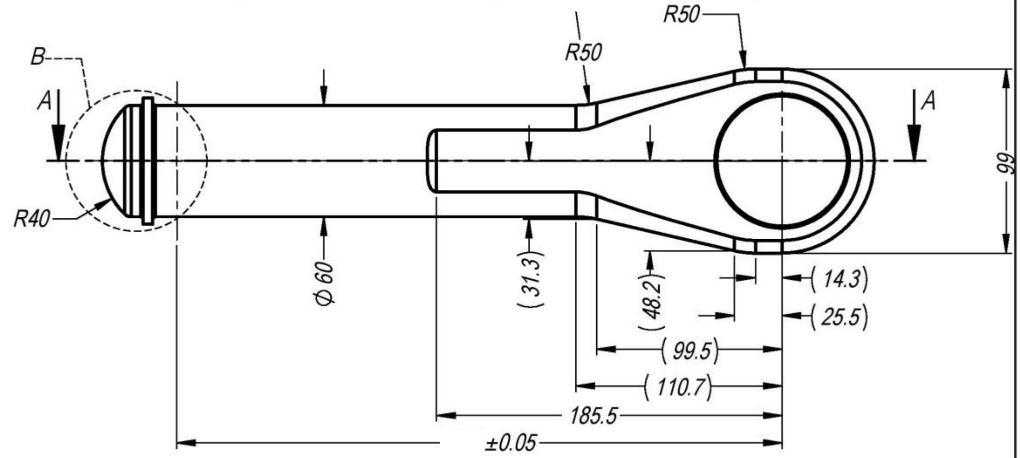




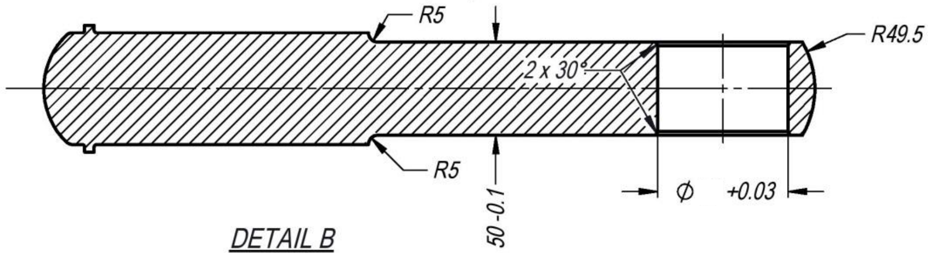


NO	PART NUMBER	QTY
1	001-01200-01-R00	1
2	001-01200-02-R00	1
3	001-01200-03-R00	2
4	001-01200-04-R00	1
5	001-01200-05-R00	1
6	SPRING_WASHER_DIN128_M5	8
7	BOLT_DIN912_M5x16	8
8	WASHER_DIN125_M5	8
9	TRELLEBORG_TURCON_GLYD_RING_PG4201000-M12N	2
10	TRELLEBORG_SLYDRING_GP7501000	2

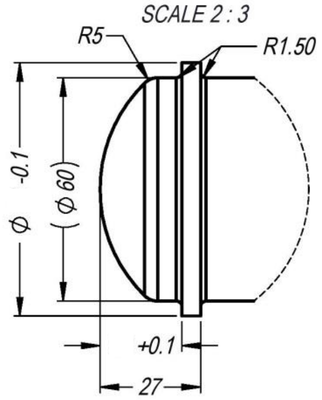
Genel Yüzey Pürüzlülüğü General Roughness: - µm	Ait Olduğu Kompleler / Complete Numbers of Part			Proje Adı / Project Name: IN-ARM SUSPENSION	Ağırlık(kg) / Weight: 13.68 — Çizim Ortamı / Drawing Env.: Solidworks 2016 Drawing
A3 — Birim Unit: mm	İsim / Name	İmza / Signature	Tarih / Date	Parça No / Part Or Ident No: 001-01200-00-R00	Malzeme / Material: ASSEMBLY
Çizen / Drawn By	Can Kutay TUÇ		x		
Ölçek Scale: 1:1 — Kontrol / Checked	Can Kutay TUÇ		x	Parça Adı / Parts Name: HYDRAULIC PISTON ASSEMBLY	Sayfa Sheet: 1/1
Onay / Approval	Can Kutay TUÇ		x		

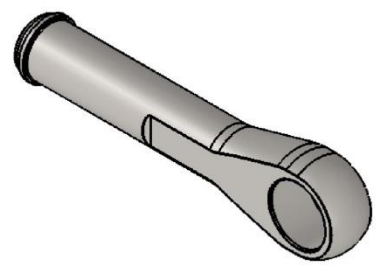


SECTION A-A
SCALE (1 : 3)



DETAIL B
SCALE 2 : 3





NOTES

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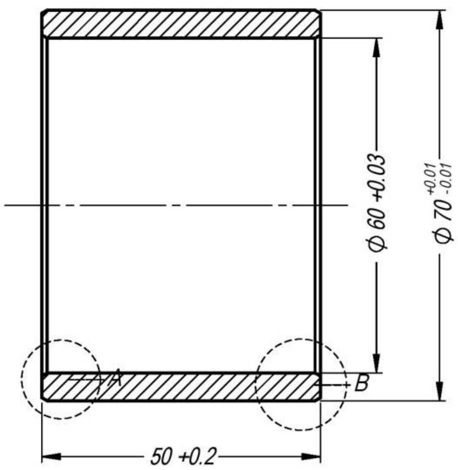
3- ZINC PLATING, BH-A-015, CLASS III, TYPE C.

TS1980-1 EN22768-1

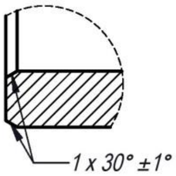
ÖLÇÜ ARALIĞI	>0.5 ≤6	>6 ≤30	>30 ≤120	>120 ≤400	>400 ≤1000	>1000 ≤2000	>2000 ≤4000
TOLERANS	±0.1	±0.2	±0.3	±0.5	±0.8	±1.2	±2

Genel Yüzey Pürüzlülüğü / General Roughness: 3.2 µm	Ait Olduğu Kompleler / Complete Numbers of Part	Proje Adı / Project Name: IN-ARM SUSPENSION	Ağırlık(kg) / Weight: 8.53
Çizim Ortamı / Drawing Env.: Solidworks 2016 Drawing		Parça No / Part Or Ident No: 001-01200-01-R00	Malzeme / Material: 1.1191 (C45E)
Parça Adı / Parts Name: PISTON ROD		Sayfa Sheet: 1/1	

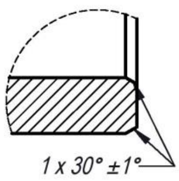
A4	Birim Unit: mm	İsim / Name	İmza / Signature	Tarih / Date
Ölçek Scale	Çizen / Drawn By	Can Kutay TUÇ		X
1:3	Kontrol / Checked	Can Kutay TUÇ		X
	Onay / Approval	Can Kutay TUÇ		X

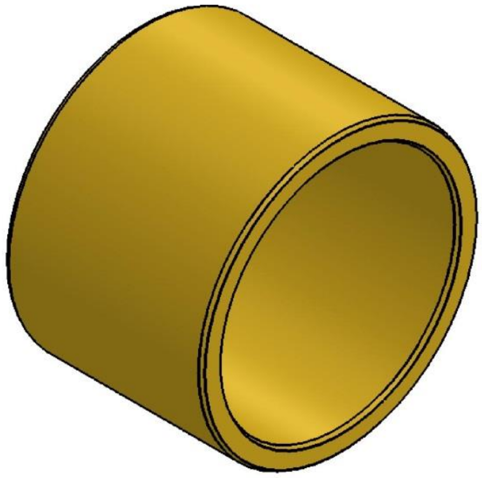


DETAIL A
SCALE 2 : 1



DETAIL B
SCALE 2 : 1





NOTES

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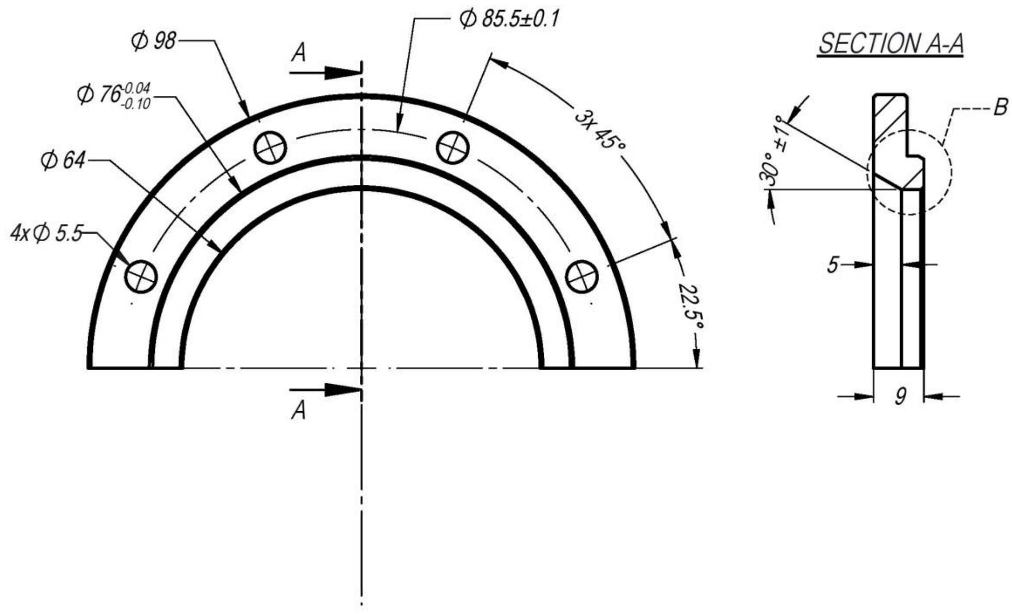
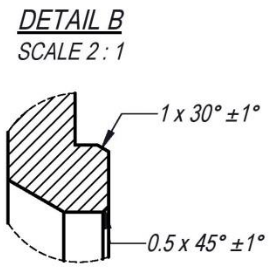
THE TOLERANCES GIVEN IN THE TOLERANCE TABLE ARE VALID FOR THE DIMENSIONS WHICH ARE TAKEN FROM 3D MODEL.

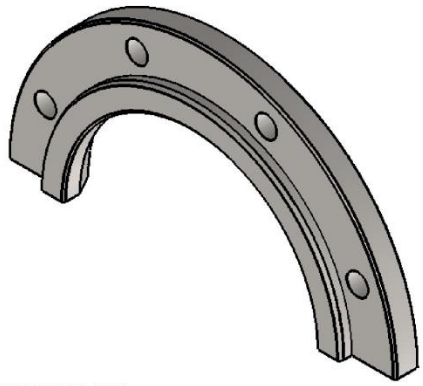
TS1980-1 EN22768-1							
ÖLÇÜ ARALIĞI	>0.5 ≤6	>6 ≤30	>30 ≤120	>120 ≤400	>400 ≤1000	>1000 ≤2000	>2000 ≤4000
TOLERANS	±0.1	±0.2	±0.3	±0.5	±0.8	±1.2	±2

Genel Yüzey Pürüzlülüğü / General Roughness: 3.2 μm	Ait Olduğu Kompleler / Complete Numbers of Part	Proje Adı / Project Name: IN-ARM SUSPENSION	Ağırlık(kg) / Weight: 0.38
Çizim Ortamı / Drawing Env.: Solidworks 2016 Drawing		Parça No / Part Or Ident No: 001-01200-02-R00	Malzeme / Material: 2.0966 (CuAl10Ni5Fe4)
Parça Adı / Parts Name: PISTON ROD BUSHING		Sayfa / Sheet: 1/1	

A4	Birim / Unit: mm	İsim / Name	İmza / Signature	Tarih / Date
Ölçek / Scale	Çizen / Drawn By	Can Kutay TUÇ		X
1:1	Kontrol / Checked	Can Kutay TUÇ		X
	Onay / Approval	Can Kutay TUÇ		X







NOTES
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2- 3D MODEL FILE WILL BE USED FOR THE DIMENSIONS WHICH ARE NOT GIVEN IN DRAWING FILE.
THE TOLERANCES GIVEN IN THE TOLERANCE TABLE ARE VALID FOR THE DIMENSIONS WHICH ARE TAKEN FROM 3D MODEL.
3- ZINC PLATING, BH-A-015, CLASS III, TYPE C.
4- SHARP EDGES WILL BE ROUNDED 0.5mm.

TS1980-1 EN22768-1

ÖLÇÜ ARALIĞI	>0.5 ≤6	>6 ≤30	>30 ≤120	>120 ≤400	>400 ≤1000	>1000 ≤2000	>2000 ≤4000
TOLERANS	±0.1	±0.2	±0.3	±0.5	±0.8	±1.2	±2

Genel Yüzey Pürüzlülüğü / General Roughness: 3.2 μm	Ait Olduğu Kompleler / Complete Numbers of Part:	Proje Adı / Project Name: IN-ARM SUSPENSION	Ağırlık(kg) / Weight: 0.11
Çizim Ortamı / Drawing Env.: Solidworks 2016 Drawing			

A4	Birim Unit: mm	İsim / Name	İmza / Signature	Tarih / Date
Ölçek Scale	Çizen / Drawn By	Can Kutay TUÇ		X
1:1	Kontrol / Checked	Can Kutay TUÇ		X
	Onay / Approval	Can Kutay TUÇ		X

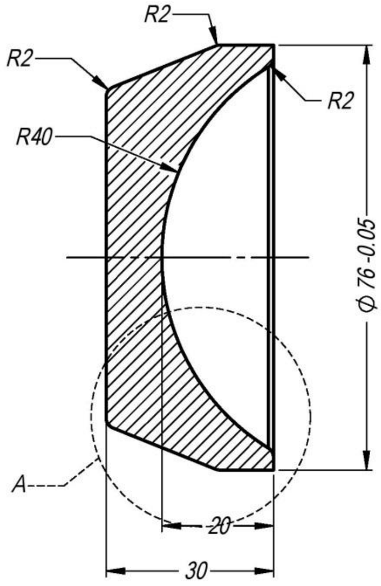
Parça No / Part Or Ident No: 001-01200-03-R00

Malzeme / Material: 1.1191 (C45E)

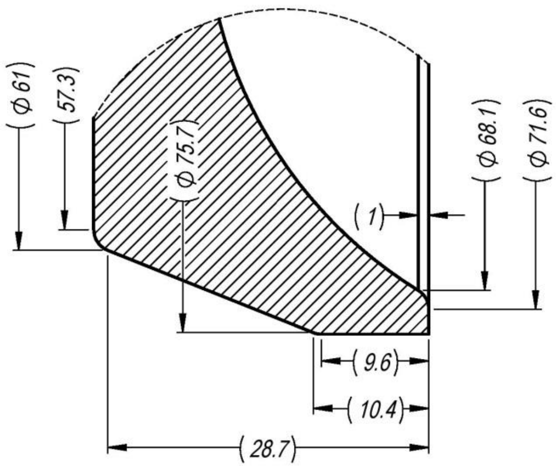
Parça Adı / Parts Name: PISTON FRONT CAP

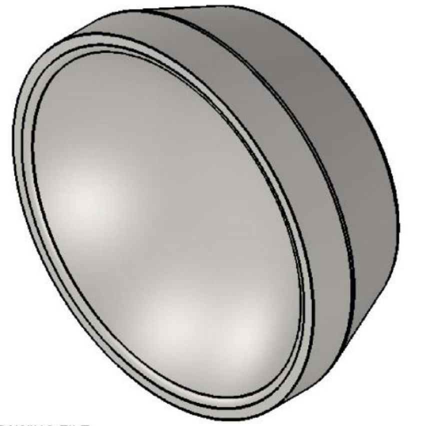
Sayfa Sheet: 1/1

	A	B	C	D



DETAIL A
SCALE 2 : 1



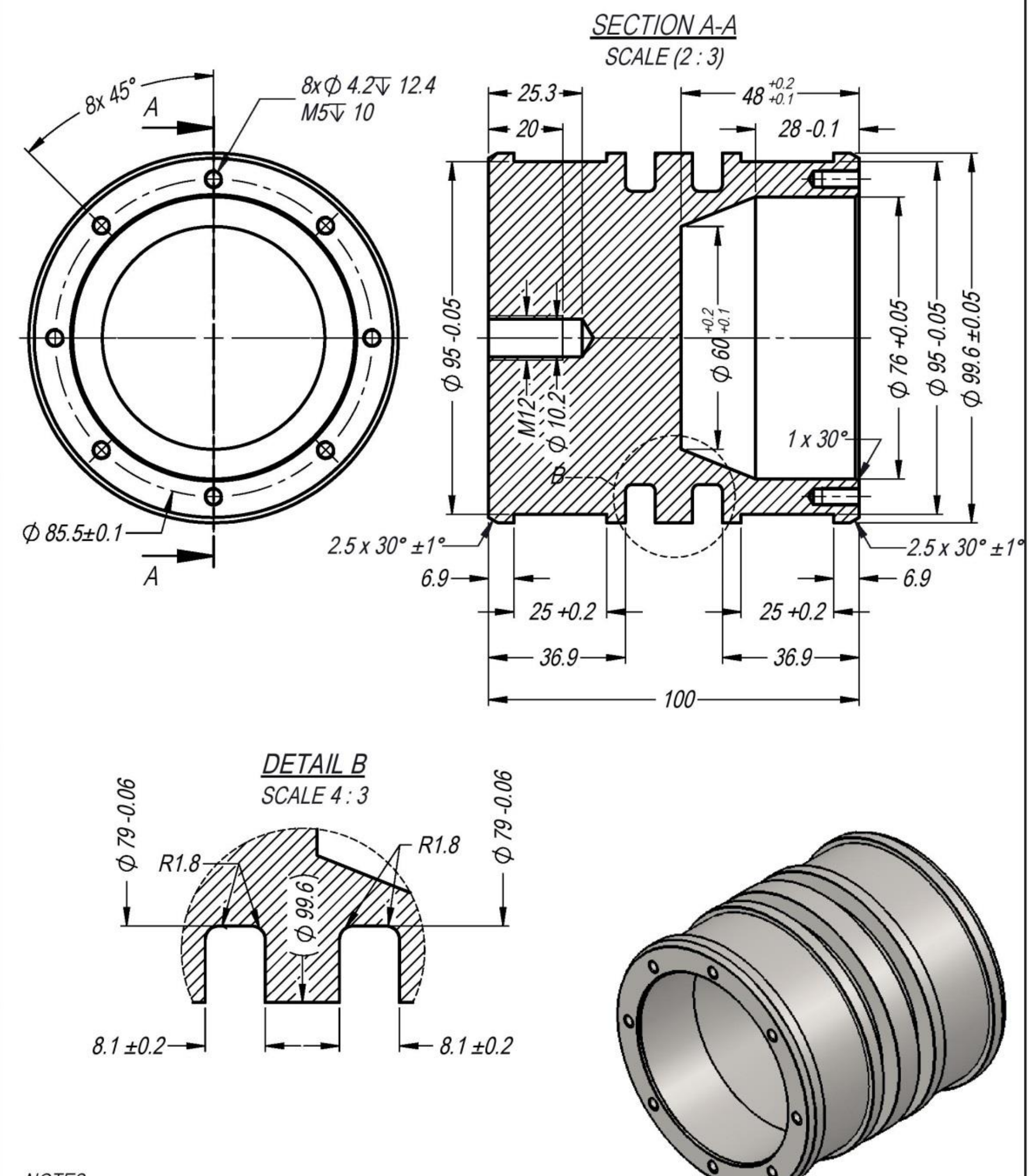


NOTES

1- 3D MODEL FILE WILL BE USED FOR THE DETAILS WHICH ARE NOT GIVEN IN DRAWING FILE.
2- 3D MODEL FILE WILL BE USED FOR THE DIMENSIONS WHICH ARE NOT GIVEN IN DRAWING FILE.
THE TOLERANCES GIVEN IN THE TOLERANCE TABLE ARE VALID FOR THE DIMENSIONS WHICH ARE TAKEN FROM 3D MODEL.
3- PART WILL BE HARDENED AND TEMPERED TO 32-38HRC HARDNESS.
4- DRY/SOLID FILM LUBRICANT COATING (COATING THICKNESS 10-25µm).
5- SHARP EDGES WILL BE ROUNDED 0.5mm.

TS1980-1 EN22768-1							
ÖLÇÜ ARALIĞI	>0.5 ≤6	>6 ≤30	>30 ≤120	>120 ≤400	>400 ≤1000	>1000 ≤2000	>2000 ≤4000
TOLERANS	±0.1	±0.2	±0.3	±0.5	±0.8	±1.2	±2

	Genel Yüzey Pürüzlülüğü / General Roughness: 3.2 µm	Ait Olduğu Kompleler / Complete Numbers of Part		Proje Adı / Project Name: IN-ARM SUSPENSION	Ağırlık(kg) / Weight: 0.60	Çizim Ortamı / Drawing Env.: Solidworks 2016 Drawing
A4	Birim Unit: mm	İsim / Name	İmza / Signature	Tarih / Date	Parça No / Part Or Ident No: 001-01200-04-R00	Malzeme / Material: 1.7225 (42CrMo4)
Ölçek Scale	Çizen / Drawn By	Can Kutay TUÇ		X	Parça Adı / Parts Name: PISTON FRICTION BUSHING	Sayfa Sheet: 1/1
1:1	Kontrol / Checked	Can Kutay TUÇ		X		
	Onay / Approval	Can Kutay TUÇ		X		



NOTES

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THE TOLERANCES GIVEN IN THE TOLERANCE TABLE ARE VALID FOR THE DIMENSIONS WHICH ARE TAKEN FROM 3D MODEL.

3- SHARP EDGES WILL BE ROUNDED 0.5mm.

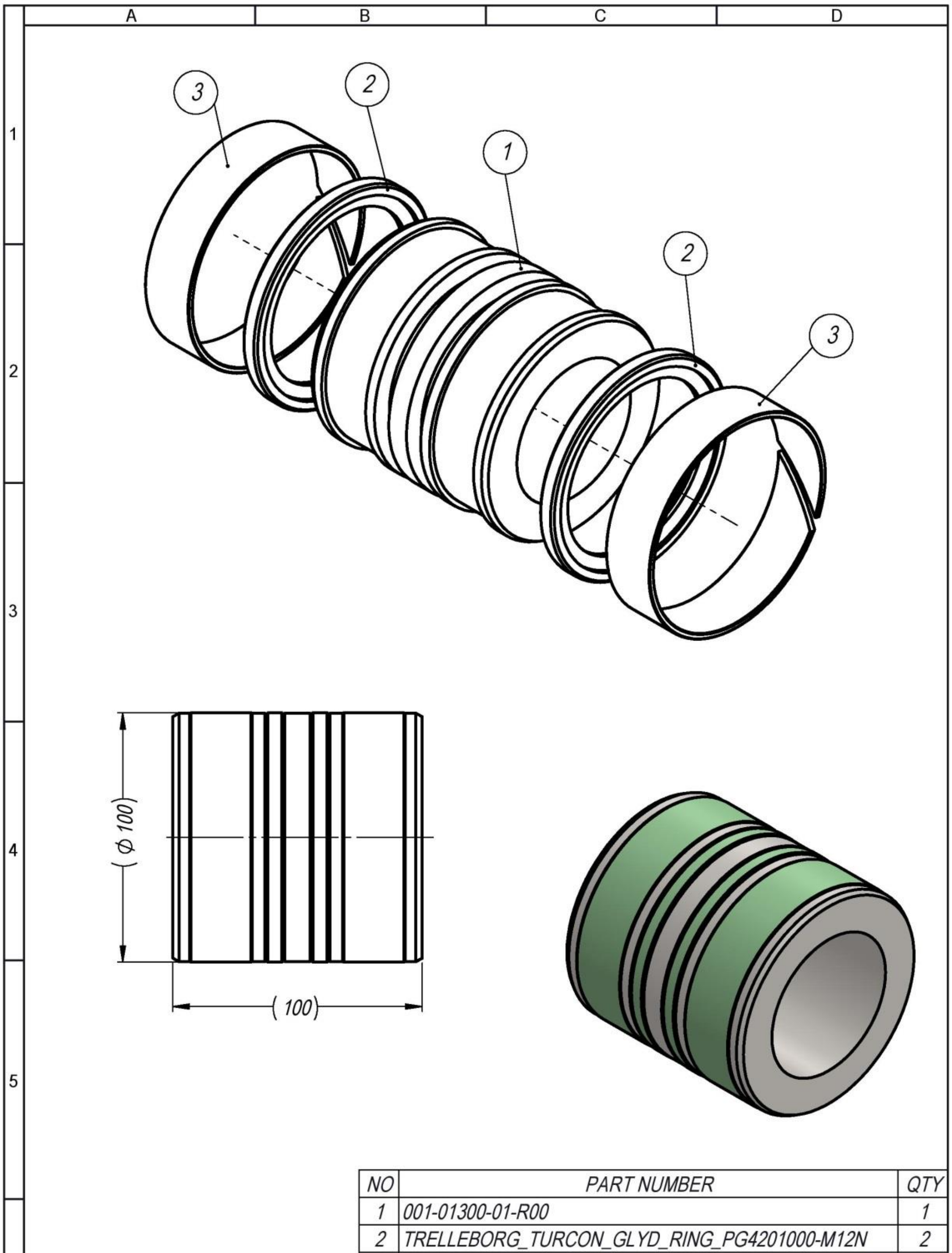
TS1980-1 EN22768-1

ÖLÇÜ ARALIĞI	>0.5 ≤6	>6 ≤30	>30 ≤120	>120 ≤400	>400 ≤1000	>1000 ≤2000	>2000 ≤4000
TOLERANS	±0.1	±0.2	±0.3	±0.5	±0.8	±1.2	±2

Genel Yüzey Pürüzlülüğü / General Roughness: 3.2 μm	Ait Olduğu Kompleler / Complete Numbers of Part	Proje Adı / Project Name: IN-ARM SUSPENSION	Ağırlık(kg) / Weight: 3.85	Çizim Ortamı / Drawing Env.: Solidworks 2016 Drawing

A4	Birim Unit: mm	İsim / Name	İmza / Signature	Tarih / Date
Ölçek Scale	Çizen / Drawn By	Can Kutay TUÇ		X
2:3	Kontrol / Checked	Can Kutay TUÇ		X
	Onay / Approval	Can Kutay TUÇ		X

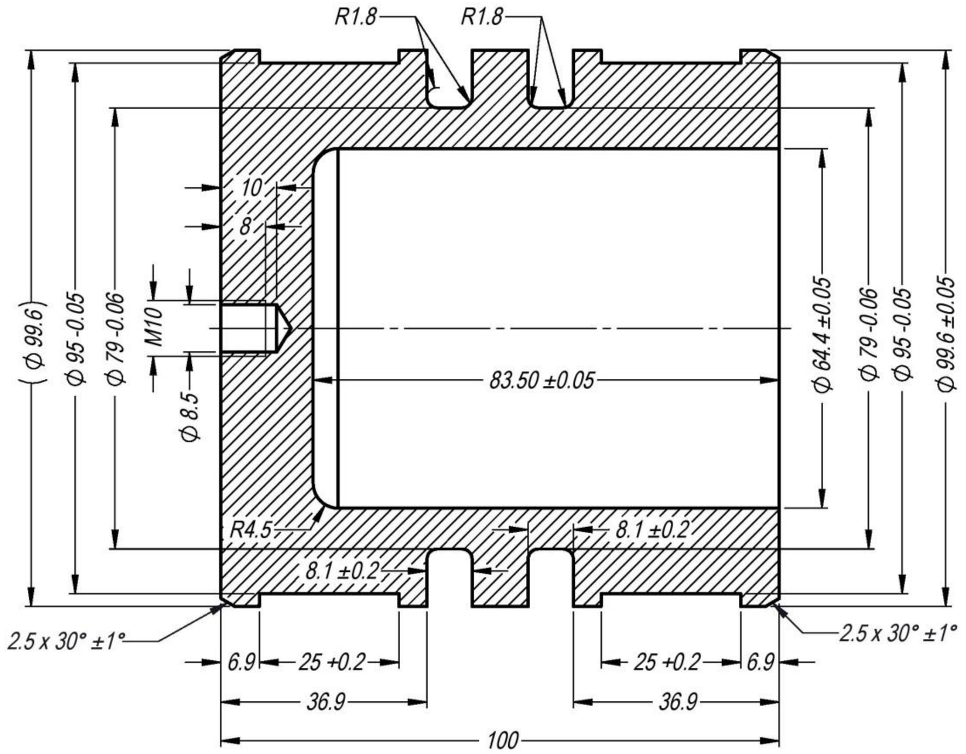
Parça No / Part Or Ident No: 001-01200-05-R00	Malzeme / Material: 1.1191 (C45E)
Parça Adı / Parts Name: HYDRAULIC PISTON	Sayfa Sheet: 1/1

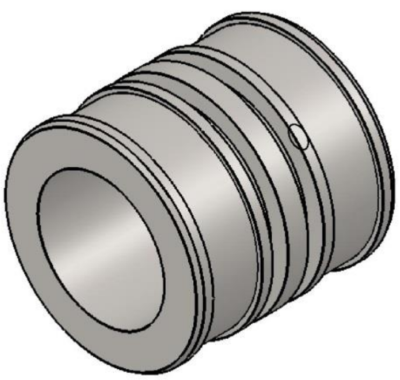


NO	PART NUMBER	QTY
1	001-01300-01-R00	1
2	TRELLEBORG_TURCON_GLYD_RING_PG4201000-M12N	2
3	TRELLEBORG_SLYDRING_GP7501000	2

		Genel Yüzey Pürüzlülüğü / General Roughness: - µm	Ait Olduğu Kompleler / Complete Numbers of Part	Proje Adı / Project Name: IN-ARM SUSPENSION	Ağırlık(kg) / Weight: 3.39	Çizim Ortamı / Drawing Env.: Solidworks 2016 Drawing
A4	Birim Unit: mm	İsim / Name	İmza / Signature	Tarih / Date	Parça No / Part Or Ident No: 001-01300-00-R00	Malzeme / Material: ASSEMBLY
Ölçek Scale: 1:2	Çizen / Drawn By	Can Kutay TUÇ		X		
	Kontrol / Checked	Can Kutay TUÇ		X	Parça Adı / Parts Name: HYDRO-GAS PISTON ASSEMBLY	Sayfa Sheet: 1/1
	Onay / Approval	Can Kutay TUÇ		X		

A	B	C	D





NOTES

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3- SHARP EDGES WILL BE ROUNDED 0.5mm.

TS1980-1 EN22768-1

ÖLÇÜ ARALIĞI	>0.5 ≤6	>6 ≤30	>30 ≤120	>120 ≤400	>400 ≤1000	>1000 ≤2000	>2000 ≤4000
TOLERANS	±0.1	±0.2	±0.3	±0.5	±0.8	±1.2	±2

Genel Yüzey Pürüzlülüğü General Roughness: 3.2 μm	Ait Olduğu Kompleler / Complete Numbers of Part	Proje Adı / Project Name: IN-ARM SUSPENSION
Ağırlık(kg) / Weight: 3.31	Çizim Ortamı / Drawing Env.: Solidworks 2016 Drawing	

A4	Birim Unit: mm	İsim / Name	İmza / Signature	Tarih / Date
Ölçek Scale	Çizen / Drawn By	Can Kutay TUÇ		X
1:1	Kontrol / Checked	Can Kutay TUÇ		X
	Onay / Approval	Can Kutay TUÇ		X

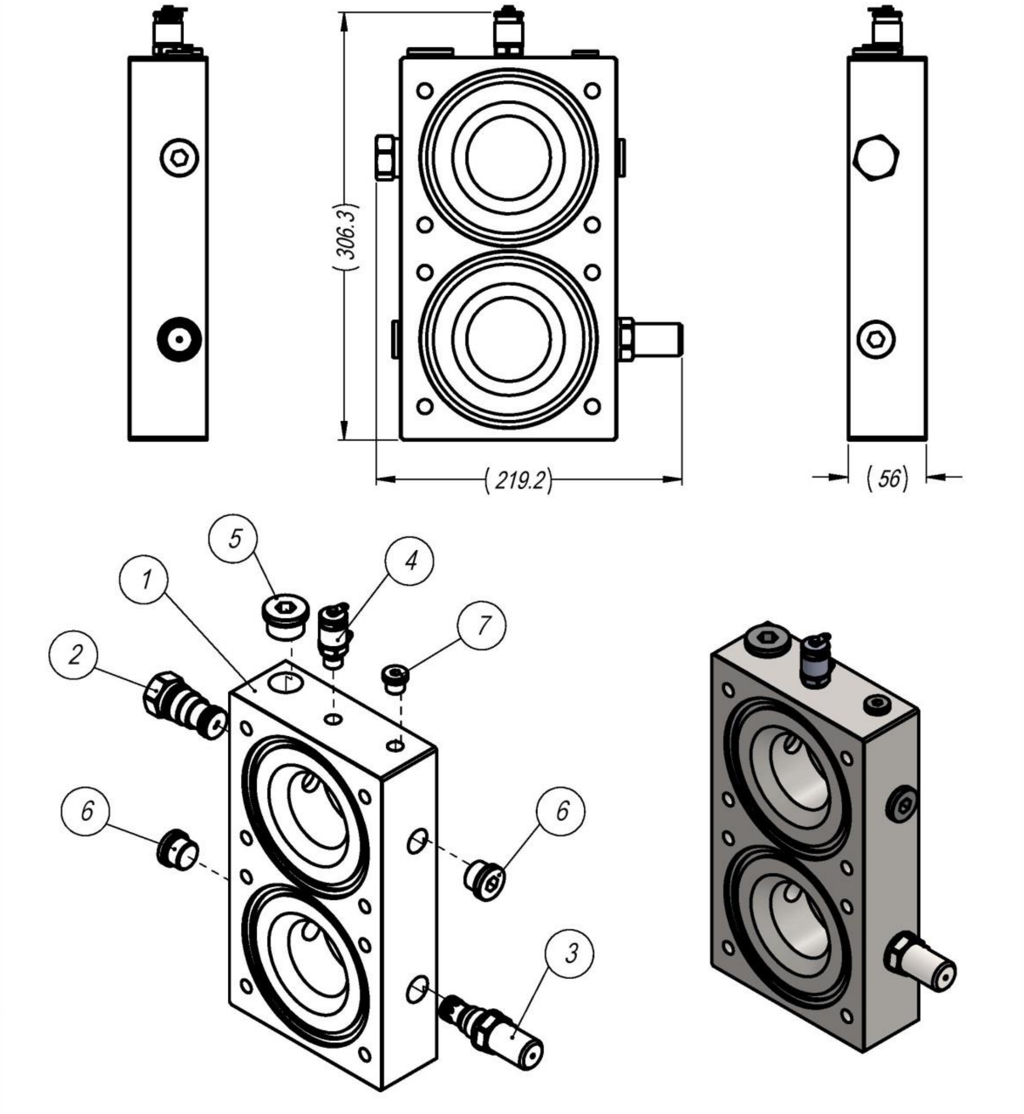
Parça No / Part Or Ident No: 001-01300-01-R00

Malzeme / Material: 1.1191 (C45E)

Parça Adı / Parts Name: GAS SIDE PISTON

Sayfa Sheet: 1/1

A B C D



NO	PART NUMBER	QTY
1	001-01400-01-R00	1
2	ORIFICE_CHECK_VALVE_SUN_HYDRAULICS_CNFCXCN	1
3	PRESSURE_RELIEF_VALVE_WANDFLUH_BCAPM22-420	1
4	CONNECTOR_SKK20-G1_4_PB	1
5	PLUG_DIN 908_G3_4	1
6	PLUG_DIN 908_G1_2	2
7	PLUG_DIN 908_G1_4	1

Genel Yüzey Pürüzlülüğü / General Roughness: - µm	Ait Olduğu Kompleler / Complete Numbers of Part	Proje Adı / Project Name: IN-ARM SUSPENSION	Ağırlık(kg) / Weight: 14.60	Çizim Ortamı / Drawing Env.: Solidworks 2016 Drawing

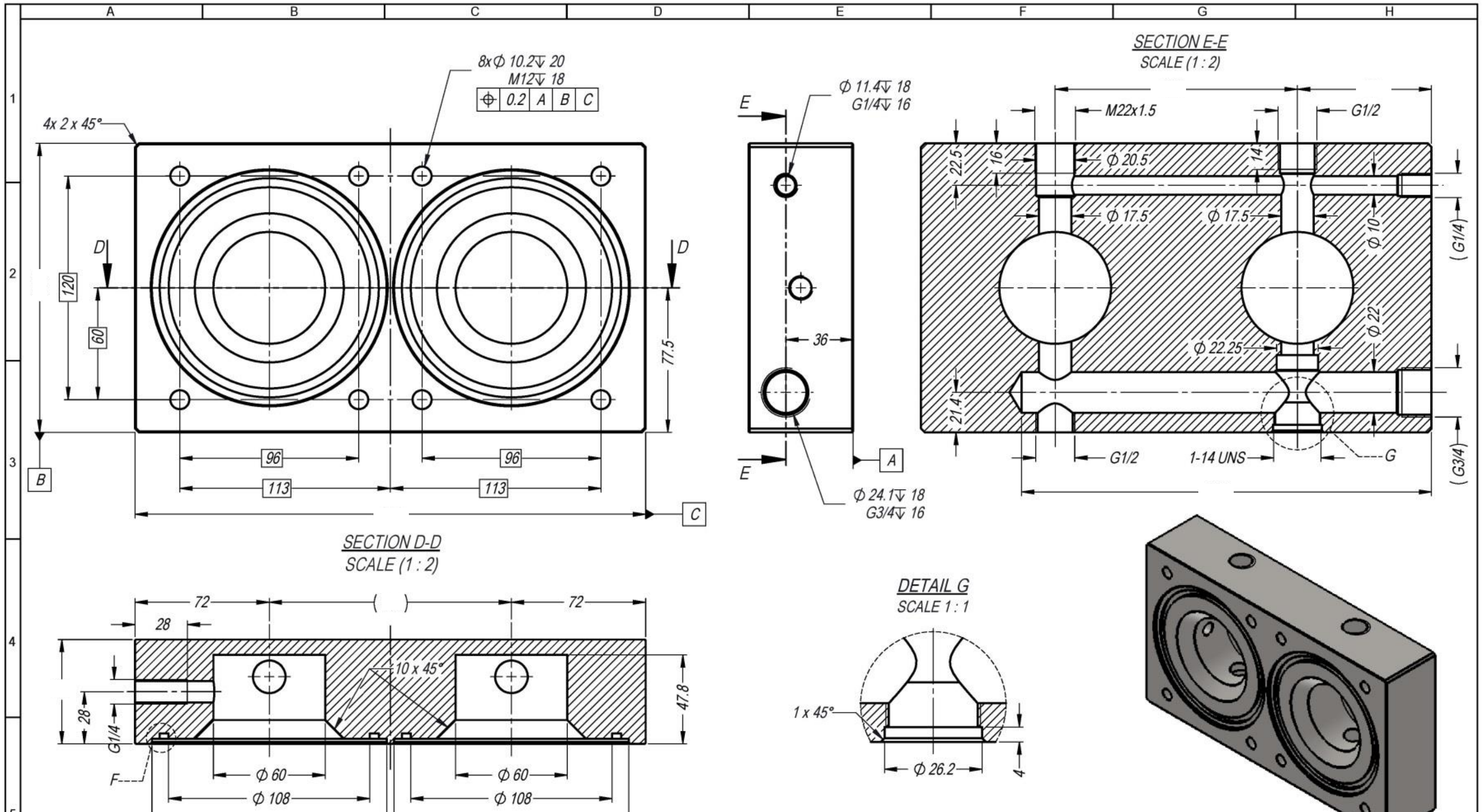
A4	Birim Unit: mm	İsim / Name	İmza / Signature	Tarih / Date
Ölçek Scale	Çizen / Drawn By	Can Kutay TUÇ		X
1:4	Kontrol / Checked	Can Kutay TUÇ		X
	Onay / Approval	Can Kutay TUÇ		X

Parça No / Part Or Ident No: 001-01400-00-R00

Malzeme / Material: ASSEMBLY

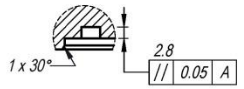
Parça Adı / Parts Name: HYDRAULIC BLOCK ASSEMBLY

Sayfa Sheet: 1/1



DETAIL F

SCALE 1 : 1



NOTES

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3- SHARP EDGES WILL BE ROUNDED 0.5mm.

TS1980-1 EN22768-1

ÖLÇÜ ARALIĞI	>0.5 ≤6	>6 ≤30	>30 ≤120	>120 ≤400	>400 ≤1000	>1000 ≤2000	>2000 ≤4000
TOLERANS	±0.1	±0.2	±0.3	±0.5	±0.8	±1.2	±2

Genel Yüzey Pürüzlülüğü / General Roughness: 3.2 µm	Ait Olduğu Kompleler / Complete Numbers of Part	Proje Adı / Project Name: IN-ARM SUSPENSION	Ağırlık(kg) / Weight: 14.50	Çizim Ortamı / Drawing Env.: Solidworks 2016 Drawing
A3	Birim / Unit: mm	Parça No / Part Or Ident No: 001-01400-01-R00	Malzeme / Material: 1.1191 (C45E)	
Ölçek / Scale: 1:2		Parça Adı / Parts Name: HYDRAULIC BLOCK	Sayfa / Sheet: 1/1	

	İsim / Name	İmza / Signature	Tarih / Date
Çizen / Drawn By	Can Kutay TUÇ		x
Kontrol / Checked	Can Kutay TUÇ		x
Onay / Approval	Can Kutay TUÇ		x