ADDIS ABABA UNIVERSITY
ADDIS ABABA INSTITUTE OF TECHNOLOGY

SCHOOL OF MECHANICAL AND INDUSTRIAL ENGINEERING
MASTER OF ROLLING STOCK

SLIDING WEAR AND CORROSION RESISTANCE OF TRAIN OVERHEAD LINE CONTACT WIRE

A Thesis Submitted To the Graduate School of Addis Ababa University in Partial Fulfillment of the Requirements for the Degree of Masters of Science

In
Mechanical Engineering
(Under Railway Engineering)

Prepared By
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Advisor
Dr. Daniel Tilahun

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DECLARATION

I, the undersigned, declare that this thesis work is my original work, has not been presented for a degree in any other universities, and all sources of materials used for the thesis work have been properly acknowledged.

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Name	Signature	Date of submission

Place: Addis Ababa

This thesis has been submitted for examination with my approval as a university advisor.

Daniel Tilahun (Dr.)	______________	__________
Advisor	Signature	Date

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By

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September, 2014

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ABSTRACT

In this study, the mechanical sliding wear and corrosion resistance property of pure copper (Cu), Cu Ag and Cu Ni Si Cr overhead contact wire were investigated by a pin-on-disc Tribometer with mechanical and electrochemical Measurement. The copper alloys were prepared in the form of pin are forced to slide on stainless steel disc at temperature of 28 ^{0}c and unlubricated condition at a sliding speed of 80km/hr under normal load up to 100 N without electric current and corrosion test also conducted in acid, rain, salt environmental condition and in notch stress. The worn surface of and wear debris as well as the corrosion from the specimens were studied by metallurgical microscopes and the weight loss measured by analytical balance. Finally, the Cu Ni Si Cr copper alloy has better wear and corrosion resistance property and also takes less purchase cost. And the material is recommended for Addis Ababa light rail transit overhead line contact wire.

TABLE OF CONTENTS

LIST OF ACRONYMS

Cu- copper

Ni- nickel

Si- silicon

Cr- chromium

Ag -silver

LRT -light rail transit

COF –coefficient of friction

Zr – zirconium

HCl- hydrochloric acid

Nacl –sodium chloride

SEM- scanning electron microscopy

EDS- energy dispersive X-ray spectrum

AC-alternative current

DC –direct current

ω -rotational speed

P-power of motor in k w

T - Torque capacity of motor created by frictional force in N mm

N - Rotational speed of disc in rpm

F_f - frictional force on the disc

r - Maximum radius of disc

μ -coefficient of friction

F_a- axial force (tensile or compressive)

C-the end condition number of shaft

α −Column action factor (for tensile or compression load)

σ_u-ultimate stress

σ_y −Yield stress

σ_t-tensile stress

σ_{all}-allowable stress

σ_a-axial stress

C- Spring index of spring

D_m - mean diameter of spring

D_w - wire diameter of spring

D -diameter of the coil of spring

P -pitch, of spring

N_a -the number of active turns of spring

L_o -free length of spring

k -stiffness of the spring

G - The shear modulus, for spring steel

Ra- Surface roughness in μ m

ρ - the density

Δw - weight loss

W -wear rate

R- Wear resistance

B_x - reaction force in the y-direction

B_y –reaction force in the y-direction

D_y – bearing force in the y-direction

D_x - bearing force in the x-direction

LIST OF TABLES

LIST OF FIGURES

CHAPTER ONE: INTRODUCTION

1.1. Background

The railway systems are becoming key-players in worldwide transport and Train transportation has several advantages on motorway transportation from the point of view of environmental impact, especially in terms of CO_2 emission, accident reduction use of land, and time travel reduction [1]. And the Addis Ababa Light Rail project is on the preparation to share this transport system, most and modern of this transport system used over head line as power supplier to the railway trains.

Over head line is a structure used in electric power transmission and distribution to transmit electrical energy along large distances using sliding contact with pantograph of rolling stock. It consists conductors (contact wires) suspended by mast or poles. For certain applications, copper alloy conductors are preferred instead of pure copper, especially when higher strengths or improved abrasion and corrosion resistance properties are required.

The service lifespan of the overhead catenary and collector strips essentially depends on (i) type of materials at contact; (ii) operating conditions such as sliding speed, contact force and current intensity; (iii) level of sparking and/or arching and (iv) environmental factors such as catenary in tunnels or in the open space.

Conventionally hard-drawn copper is often used as overhead catenary for traction systems because of its excellent electrical and thermal conductivities and moderately low price but its limitations are low hardness, susceptibility to electrical sliding wear and atmospheric corrosion which lead to shortening of its service life, interruption of the system, and safety problems [4] and copper has the highest electrical conductivity rating of all non-precious metals, it is an essential property in electrical wiring systems.

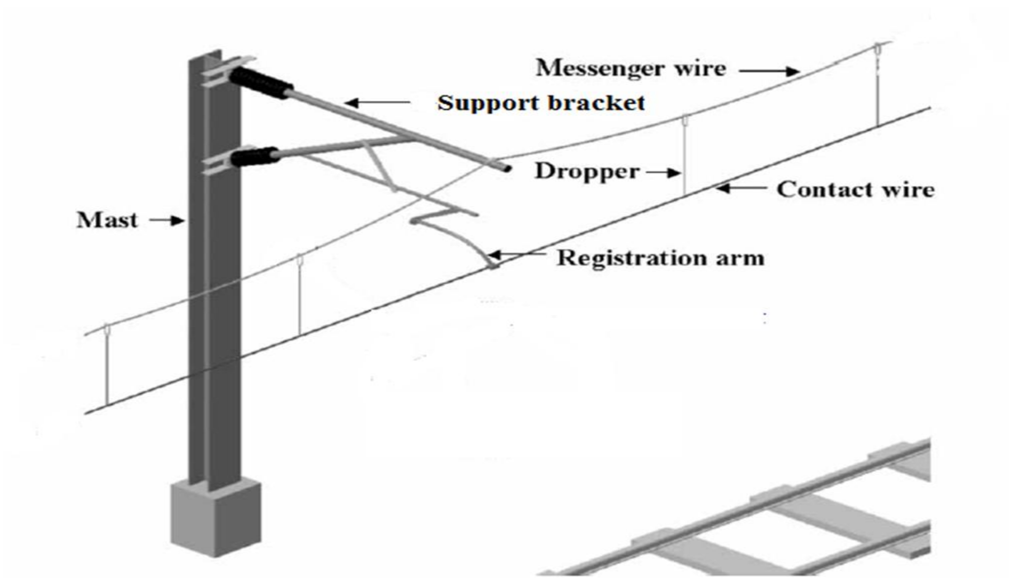


Figure1: Parts of the overhead line systems

Copper is easily soldered to and has good mechanical characteristics including tensile strength, toughness and ductility. Due to its low coefficient of thermal expansion and high tensile strength, copper finds widespread use in overhead transmission lines. [8] Not all the overhead line is copper; some fittings are stainless steel so that the carbon pantograph strip moves from copper to stainless steel and to copper. Wear depth of stainless steel was lower than copper. Many of the wear process at the rail-wheel contact apply also to the overhead line power supply. And electrical transmission-arcing can contribute greatly to wear [5]. However, relative to pure copper, the higher strength and corrosion resistance benefits that are offered by copper alloys are offset by their lower electrical conductivities.

Therefore, this study focuses on getting that have relatively good wear and corrosion resistance and conductivity property and also cheap, easily accessible from the market overhead contact wire using Cu-Ni-Si-Cr copper alloy material instead of Addis Ababa Light Rail Transit Cu Ag contact wire. Even if in the past enough researches not done on this area, but the Korean society for railway researchers tried to improve sliding wear and corrosion resistance of copper overhead contact wire using age hardened copper alloy using pin on disc tribometer [4], is a simple advanced mechanical surface testing instrument to do a dynamic testing for the friction and the wear[9], they relatively get good electrical conductivity and wear resistance alloy, but they still can’t improve or come up with near to 100% conductivity of copper alloy.

Remark: in figure 2 Disc represents the pantograph and the specimen (pin) represents the contact wire

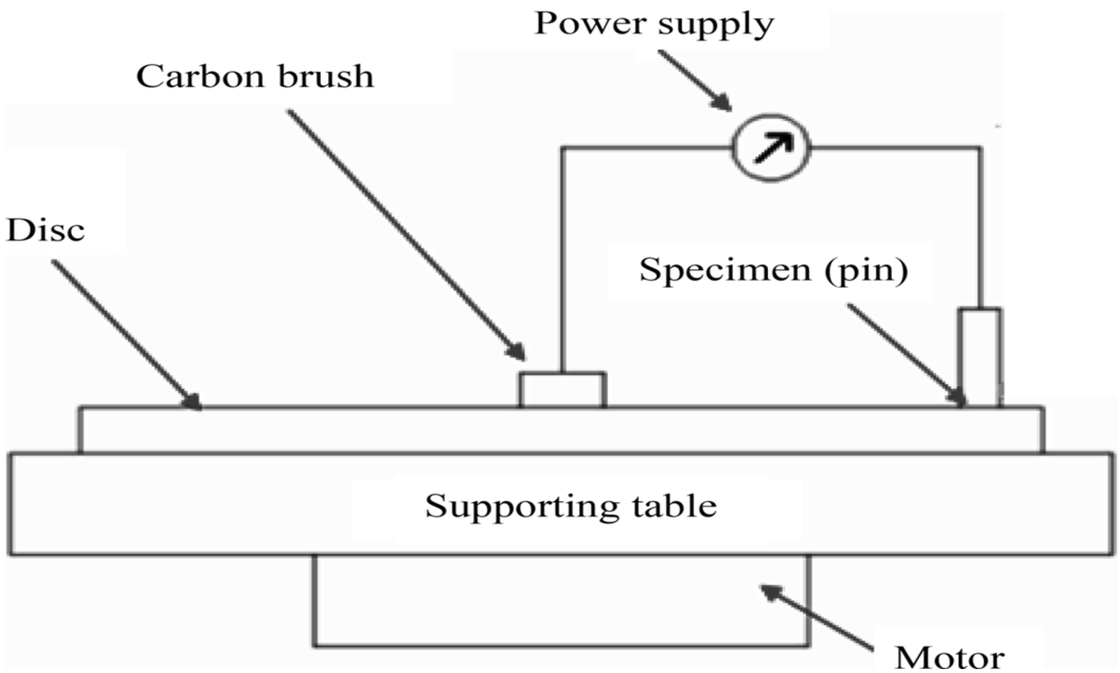


Figure 2: Schematic drawing of a pin-on-disc tribometer [4]

1.2. Statement of Problem

In today's Ethiopian transportation system, the railway transport system is under construction, i.e. it is new. Therefore, we have to accept this technology with maintenance cost minimization by improving property of overhead contact wire. The main problem for this contact wire is wear and loosing conductivity. As can be seen from few research papers, many engineers tried to improve this problem, the only thing they have done is, specify the various types of copper and copper alloy conductors based on their advantages and disadvantages for a specific electrical application, but they couldn't improve the wear rate without reducing conductivity[3,4]. And when we come to our country case, the Ethiopian railway corporation is already on erection process of overhead line system which means, the copper silver contact wire and pure copper supports, but their contact wire material has poor wear and corrosion resistance property relative to the copper alloy material that have good wear and corrosion resistance property elements or metals like chromium(Cr), nickel(Ni), silicon(Si) etc and each element cost of CuAg alloy is expensive compare to element mentioned before. Therefore, I interested to compare and see the effect of Cu, CuAg and CuNiSiCr copper based alloys to suggest the rich material better than CuAg alloy for Addis Ababa LRT overhead contact wire.

1.3. Objective of the Study

1.3.1. General objective

The major objective of this paper is finding alternative high wear and corrosion resistance, and conductive copper based over head contact wire for Addis Ababa light rail transit overhead line.

1.3.2.Specific objectives

The specific objectives of the research are:

- Manufacture pin and disc test pieces.
- Design and construct pin on disc tribometer machine for simulation sliding contact of pantograph and contact wire.
- Modeling the pin on disc tribometer machine by Catia V5 software.
- Finding wear and corrosion resistance copper alloy material.

1.4. Scope and Limitation

1.4.1 Scope

In this research, as stated earlier the mechanical and electrochemical wear resistance property of Cu, CuAg and CuNiSiCr copper alloy are carried out due to different load and environmental condition.

1.4.2 Limitation

During the study of this research, the following limitation were happened

- Financial support and test specimen did not get on time, this leads the research take long time

- Machine parts like motor not available by design specification, this forced to use the available material and make some modification on test condition, during test the force decrease from 100N to 10N and the rotational speed from various to fixed or constant 5898rpm
- Some material did not get by laboratory grade to make pins, industrial grade materials were used during preparation, this affect the material by impurities (not needed material)
- Because of small material preparation place shortage, this material melted by oil furnace under not protected environment, this leads porosity and vapor of some element.
- Shortage of enough research on this area and data, the data given by Ethiopian Railway Corporation are placed in range not specific, by this research the maximum value of data was taken.
- The conductivity test not conducted because of un availability of test machine

1.5. Organization of the Paper

This thesis is organized in six chapters. In the first chapter, background and justification of this thesis work and the objectives to be achieved are discussed. In chapter two, a review of literatures relevant to this thesis work, which have been investigated by different researchers, are given. Chapter three is about design of pin on disc tribometer machine for wear analysis. Chapter four experimental method and condition and also, in chapter five, results of the analysis are summarized and discussions are made based on the outputs of the experimental analysis. Finally, chapter six gives conclusion and recommendation achieved from this thesis work and propose future work in this field of study.

CHAPTER TWO: LITERATURE REVIEW

Overhead Catenary constitutes an important traction system of electrical conductors used in conjunction with sliding pantograph current collectors to supply electrical energy to moving locomotives. The increasing speed of modern high-speed locomotives becomes a challenging problem in the design of electric traction systems over the world. In recent technological developments of electric traction systems, major efforts have been devoted to speeding up locomotives, prolonging lifetime and reducing maintenance costs of the overhead Catenary and collector strips. To withstand the harsh service condition in real application, electric contact materials for the overhead Catenary and collector strips should possess high hardness and mechanical strength, high electrical sliding wear and corrosion resistance and excellent electrical conductivity.

C.T. Kwok [4] studies The service lifespan of the overhead catenary and collector strips essentially depends on (i) type of materials at contact; (ii) operating conditions such as sliding speed, contact force and current intensity; (iii) level of sparking and/or arching ; and (iv) environmental factors such as catenary in tunnels or in the open space . Conventionally, hard-drawn copper is often used as overhead catenary for traction systems because of its excellent electrical and thermal conductivities and moderately low price but its limitations are low hardness, susceptibility to electrical sliding wear and atmospheric corrosion which lead to shortening of its service life, interruption of the system, and safety problems.

Age-hardenable copper alloys are dilute alloyed with elements such as Cr, Zr, Ag, Mg and Be etc with limited solubility. Through age hardening, the mechanical and tribological properties of these copper alloys can be enhanced while a high level of electrical conductivity can be preserved. In previous research less effort has been put on the electrical sliding wear performance of the new overhead catenary materials, and metallurgical study for the wear process, such as the morphology of the worn surface and the debris formed, is inadequate [4].

Corrosion is the electrolytic action of moisture and other dissolved ions of the atmosphere on the metals. The corrosive effects of the outdoor environments, for instance, salty coastal atmosphere, acid rain and icing, present unique challenges to overhead catenary and lead to degradation and eventually to system failure.

With the technological developments of electric railways, speedup of train and reduction of cost to maintain the facilities are strongly required. Major efforts have devoted to solve these issues to meet the expectations of people. The contact wire is one of the factors, which can greatly affect the speedup of the train and the cost of maintenance. To improve the quality of the contact wire, new materials should be developed. The contact wire made with the new materials should have a low wear rate and an excellent combination of high strength and high conductivity.

Mostly, Wear is composed of the several processes that occur in metal sliding situations. The processes possibly include metal transfer, film formation and removal, debris generation and cyclic surface deterioration. All of these affect the tribological behavior and depend greatly on the sliding materials, the contact geometry, thermal effects (friction and the electric field), the chemical environment of the contact and the mechanical parameters of the system [9].

The S.G. Jia a[15] group studied Cu–Ag–Cr alloy is a kind of latest and promising contact wire material for the high-speed electrified railway because of the wear mechanisms between the contact wire made of the Cu–Ag–Cr alloy and the strips have not been systematically studied so far. Therefore, it is necessary to carry out such studies for them.

The sliding wear behavior of the Cu–Ag–Cr alloy contact wire was studied using a specified sliding wear tester in this paper. The Cu–Ag–Cr alloy wire was slide against a copper-based powder metallurgy strip, which was used as a contact strip on a pantograph of an electric railway vehicle in a train system.

The Cu–Ag–Cr alloy wire is a newly developed material to be used as a contact wire for high-speed electrified railway. Cu–Ag–Cr alloy is a promising contact wire material for high-speed electrified railways, which has an excellent combination of mechanical strength and electrical conductivity Compared with a Cu–Ag contact wire under the same conditions, the Cu–Ag–Cr alloy wire had much better wear resistance**.**

Additives to the copper generally result in a reduction in its conductivity. The copper is alloyed with small quantities of one or more substances in order to attain specific properties without varying its basic character. Adding tin, iron or chromium makes the copper stronger. Sulphur or tellurium improves its cutting properties. Adding silver, cadmium, tin or tellurium increases the softening temperature and improves its creep strength. Nickel additions result in great strength and improved resistance to corrosion.

Materials approved by researchers Based on consideration of wear resistance, electrical conductivity and safety, Cu Cr Zr is a promising candidate as the contact wire material. From the following material mentioned in the table [4]:

Table 1 Composition and Properties of Copper and its Alloys

Alloy	Composition (Bal. Cu)	Electrical conductivity	Density (g/cm^3)	Hardness (Hv)
Cu (C11000)	0.04% O	100% IACS, 58 MS/m	8.90	102
CuCr (C18200)	1.2% Cr	74% IACS, 43 MS/m	8.89	162
CuZr (C15000)	0.25% Zr	80% IACS, 47 MS/m	8.89	132
CuCrZr (C18150)	1.4% Cr, 0.12%Zr	74% IACS, 43 MS/m	8.89	168
CuNiSiCr (C18000)	2.5% Ni, 0.8% Si, 0.5% Cr	29% IACS, 17 MS/m	8.84	234
CuBe (C17200)	2% Be	23% IACS, 13 MS/m	8.36	342
CuBeNi (C17510)	0.4% Be, 1.5% Ni	44% IACS, 25.8 MS/m	8.83	242

Tribometer and its type

A tribometer (tribotester) is the general name given to a machine or device used to perform tests and simulations of wear, friction and lubrication which are the subject of the study of tribology. Often tribometers are extremely specific in their function and are fabricated by manufacturers who desire to test and analyze the long-term performance of their products.

By theoretical analysis of friction process and wearing and different tribometer construction, it could be concluded that the tribometrical problems are related not just to tribology, but too many other theoretical sciences (dynamics, construction theory, electronics and other). All this implies to necessity of multidisciplinary approach to this problem, from both theoretical and engineering aspects.

A large number of tribometers for different applications were realized by Faculty of Mechanical engineering in Kragujevac in Metal processing and tribology laboratory. Design of this tribometer is realized by Yugoslav Tribology Society and Faculty of Mechanical Engineering in Kragujevac [17].

Tribology based machine design caused major contribution in development of compact and low weight machinery. Tribotronics applies to the integration of tribology and electronics. Tribotronics or active tribology based on adaptive performance is thought of as being critical in the implementation of smart machine concepts.

The conditions of a tribological system are monitored by sensors that provide information on i.e. temperature, pressure, friction, vibration, oil properties such as total acid number or additive depletion and other parameters of interest. The signals from these sensors are processes and transmitted to the control unit. In the computational or decision making part, real-time software based on tribological algorithms calculates the required action which is then implemented by actuators. Such a system is thus independent and self-adjusting. This allows for on-line change of the tribological system for the best performance. The key principle of tribology is the practice of additional so-called loss outputs such as friction, wear and vibration [16].

Different types of Pin on disc tribometer observed from different literature based on their function and for this research model of the machine is taken from literature [16] by its simple design but the load application and position adjusting system are different.

A. Tribometer TPD-04

Tribometer TPD-04 enables simulation of different contact and test types. Special device enables pin on disk, circular and linear reciprocating test types. The main purpose of tribometer was investigation of friction and wear of polymer materials with or without lubricant according to appropriate standards.

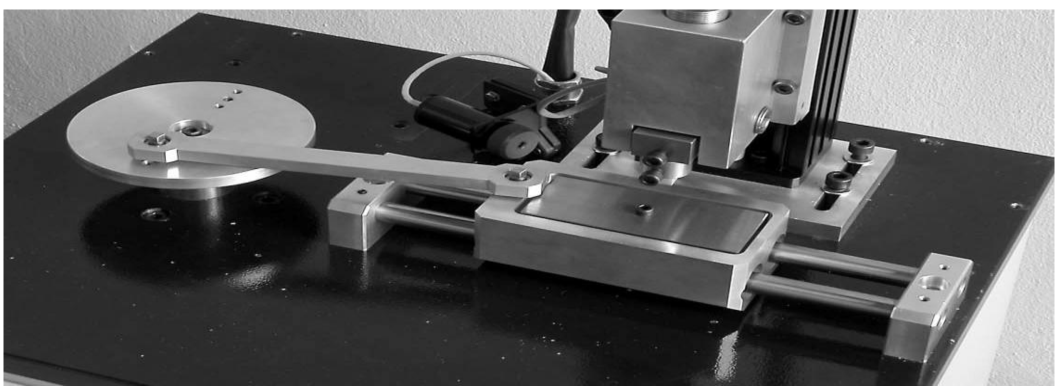


Figure 3: Unit for reciprocating moving [17].

B. Friction oscillations with a pin-on-disc tribometer

Oscillations on friction force tracings recorded during pin-on-disc experiments were found to be a result of non-uniform surface features and lubrication conditions along the circular wear track.

The oscillations were not due to stick slip. Spacing between peaks and valleys on the tracings were observed to correspond directly to the rotations of the disc specimen. The characteristics of the friction force oscillations were more clearly revealed when the chart speed was increased or when the disc rotation was slowed.

The amplitude of the oscillations changed with continued sliding. Results indicated that the coefficient of sliding friction for the materials tested under boundary or unlubricated conditions should more properly be reported as a range of values rather than one single nominal value. Reporting a range of values provides additional information on the stability of sliding conditions and the uniformity of lubrication for the tribosystem [18].

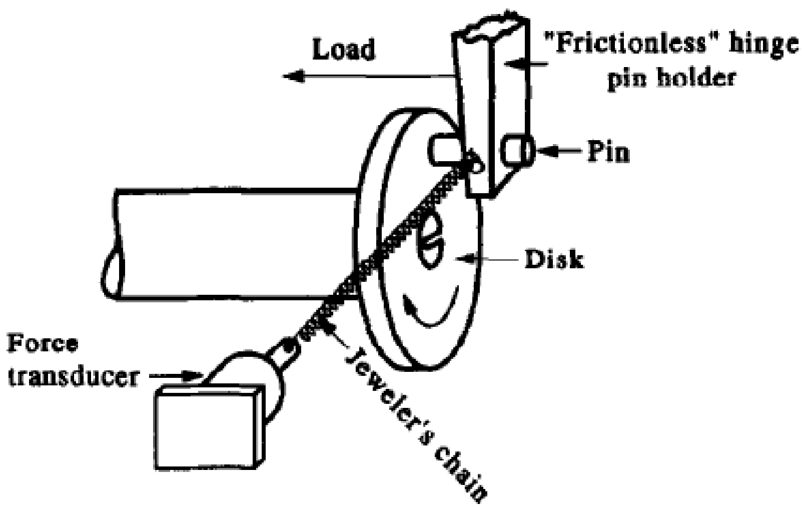


Figure 4: schematic diagram of elements of pin on disc

C. Tribotronic system on Pin-On-Disc (POD) Tribometer

Focusing on friction measurement using load cell. The analysis conducted using MATLAB software to measure Coefficient of Friction (COF) of 2 sample types in order to prove the validity of the measurement. The 2 samples are lubricant (Shell Helix Fully synthetic oil) and lubricant (Shell Helix Fully synthetic oil) with additive. It is revealed that the measurement of the lubricant with additive shows better COF (0.006) than lubricant without additive, COF of 0.02.

Mechanical arrangement

Arrangement of the load cell on top of the POD is shown in Figure 5. Basically a stationary contact pin hold by an elastic type arm that can be extended to almost half diameter of a disc under it. The arm is also connected by high tension string wire attached with a weight holder. The disc is rotated electrically and controlled by motor drive. The disc rotation is measured in RPM. The contact pin is hold into a holder that is attached to an arm that can be slide the arm is fixed with a load cell to detect the sliding force. When the disc is rotating and with a load applied on the pin, the contact between the pin bottoms with the disc surface will cause a sliding force that is detected by the load cell and read by data logger [16]

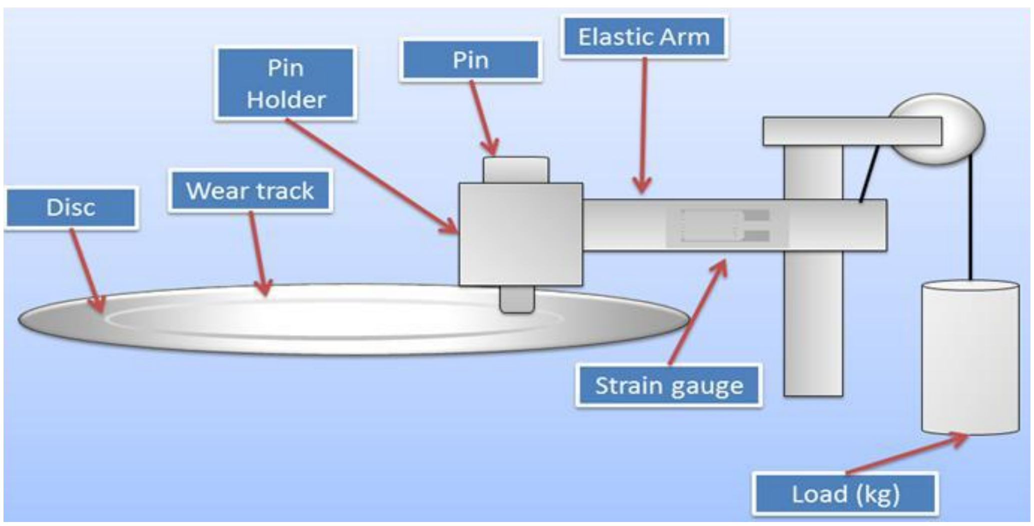


Figure 5: Load cell arrangement on top of POD system. [16]

Schematic diagram and sectional dimensions of LRT contact wire

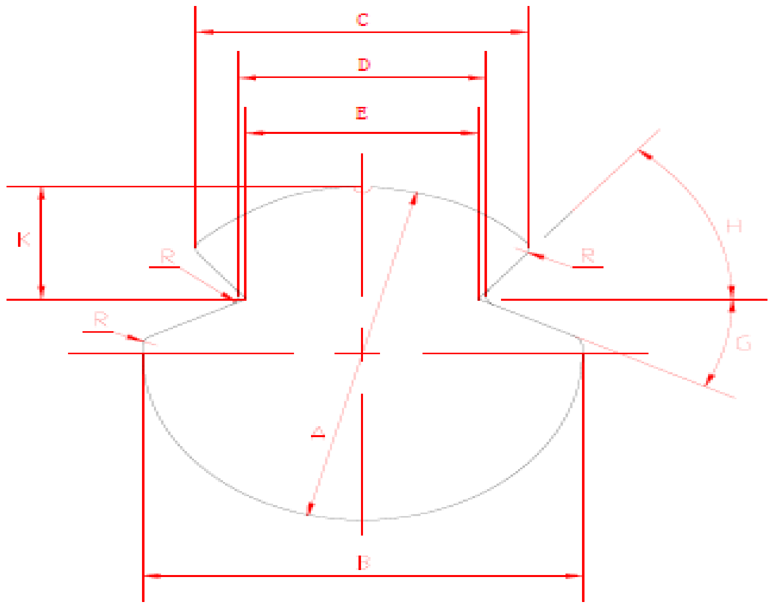


Figure 6: Schematic diagram of LRT copper alloy contact wire section [1]

In this paper, the dimension of pins manufactured by considering LRT contact wire size

Table1: Main sectional dimensions of LRT contact wire [1]

Size / Type	A (mm) ±1%	B (mm) ±2%	C (mm) ±2%	D (mm) +4% -2%	E (mm)	K (mm)	R (mm)	G(°) ±1°	H(°) ±1°
150mm² silver-copper alloy contact wire	14.40	14.40	9.71	7.24	6.80	4.00	0.40	27	51

In this paper the experimental procedures adopt from the following papers

S.G. Jia [15], Wear tests were conducted under laboratory with a special sliding wear apparatus, which simulated the tribological conditions of sliding current collectors on overhead wires in the railway system. The Cu–Ag–Cr alloy wire was slid against a copper-based powder metallurgy strip under unlubricated conditions. The same strip as those in the train systems was used. Worn surfaces of the Cu–Ag–Cr alloy wire were analyzed by scanning electron microscopy (SEM) and energy dispersive X-ray spectrum (EDS).

C.T. Kwok [4], the electrical sliding wear and corrosion resistance of pure copper (Cu) and six age-hardened copper alloys (CuCr, CuZr, CuCrZr, CuNiSiCr, CuBe and CuBeNi) were investigated by a pin-on-disc tribometer and electrochemical measurement. Various copper-based alloys in the form of cylindrical pin were forced to slide against a counter face stainless steel disc in air under unlubricated condition at a sliding velocity of 31 km/h under normal load up to 20 N with and without electric current. The worn surface of and wear debris from the specimens were studied by scanning electron microscopy. Both mechanical wear and electrical arc erosion were the wear mechanisms for the alloys worn at 50 A.

As can be seen on the above, the researches focus on developing materials for train overhead line contact wire, wear mechanism and design tribometer to found wear and friction on the surface, to get results the experiment was conduct. And this research will perform using those and related literatures. And the aims of present study are to investigate the chemical and mechanical sliding wear behavior of Cu, CuNiSiCr and CuAg age-hardened copper-based alloys under different load and environmental conditions. In addition, the corrosion behavior of the alloys in 3.5% Nacl solution, HCl acid 5PH acidity value, mostly expected in developed country 5-5.5PH acid value rain because of their industries, cars and others that out harmful gases, but for this thesis the extreme value was taken because of our country low carbon effect, and also the alloys in rain water and in notch effect stress studied.

CHAPTER THREE: DESIGN AND MODELING OF PIN ON DISC TRIBOMETER MACHINE

3.1. Design Analysis

During designing following points are considered:

- The design should be simple and the construction should be at minimum cost.
- The machine and components should be easy for human visualization.
- The component parts should be easily replaceable in case of any damage. And
- the machine construct for wear analysis purpose

In the design analysis part the following components of pin on disc tribometer machine will be designed for best and safe operation. The pin on disc tribometer machine is made up of the following components:

- Electric motor
- disc and pin(specimen)
- Shaft
- Base support and frame
- Control unit(speed or voltage controller)

The above components are modeled by Catia V5

3.2. Disc selection

This disc is the test specimen and part of the pin on disc tribometer machine

Size: 200mm diameter and the length is free but for this research machine structure up to 20mm enough and the size (diameter) chosen by considering having different wear truck or radius

Material: stainless steel

The disc material is harder compare to actual material of contact strip and its hardness greater than copper alloy

3.3. Pin selection

There are three different alloy materials selected for wear rate comparison purpose (cu, Cu Ni Si Cr and Cu Ag alloy)

The pins are prepared by 13mm diameter and 13mm length,

This size adapted from actual contact wire size and it is also used in previous research

The material chosen by the consideration of their good wear and corrosion resistance properties

Table 2: Chemical composition of copper alloy

Material	Chemical composition in %			
	Cu	Ni	Si	Cr
Cu	99.8% with 0.04% O_2			
CuNiSiCr	96.3 with 0.04% O_2	0.94	0.19	0.003
CuAg	By ERC specification (99.3Cu-0.08Ag)			

3.4. Selection of DC Motor with Speed Variation Control System

The DC motor is a machine that transforms electric energy into mechanical energy in form of rotation and it is the main part of this machine to rotate the disc

The operation of a 24v DC motor requires the presence of the following elements:

- A power supply(three phase or single phase)
- DC inverter, it can convert AC to DC and can control the speed variation(if there is the accesses to get this part) or variable voltage power supply(speed controlled by voltage variation)

  Or

Can create a direct connection with constant speed like used in this thesis because of unavailability of speed control devices

- Power source
- Breaker (has less voltage and current from the source)
- Transformer (to reduce 380v or 220v to 24v)
- Rectifier (to change 24v AC to 24v DC)
- Switch (to on/off the motor)

Direct-current (DC) motor is preferable over the other types due to:

- Overload safe, Motor cannot be damaged by mechanical overload [21].
- Locally available motor
- Can control the speed variation using inverter or variable voltage power supply to change the wear truck radius
- Can get Maximum Motor speed

Analysis of Dc motor rotational speed

The Dc motor rotational speed taken by calculation

Input data: v =the vehicle speed: 80km/hr, design speed of Addis Ababa LRT

r =100mm, radius of the disc

Output: The rotational speed of the motor

$$\omega = {}^{v}/_{r} \quad \ldots\ldots 1$$

$$\omega = \frac{80km/hr}{100mm}$$

$$= 222.2\text{rad/sec}$$

But, $1\text{rpm} = \frac{2\pi rad/sec}{60}$

Therefore,$222.2\,rad/sec = 2121.854rpm$, minimum rotational speed at maximum radius of disc and by considering the working area on the disc

Let's take r=50mm to get maximum rotational speed

$$from\ equation\ 1 \quad , \quad \omega = \frac{80km/hr}{50mm}$$

=444.4rad/sec

Change to rpm by the above method

$$\omega = 4243.71rpm$$

Therefore , the rotational speed increase when the wear truck radius decrease, but for this test the constant speed is taken because of unavailability of motor and speed controller by the design specification.

However for the design purpose, to get the minimum power capacity of motor the following calculation must be done.

$$T = \frac{9.55x10^6\ P}{N} \qquad \text{.........}2$$

Where

P= power of motor in kW

T = torque capacity of motor created by frictional force in Nmm

N = rotational speed of disc in rpm

Torque created by frictional force

$$T = F_f\ r \qquad \text{.........}3$$

r is maximum radius of disc, 100mm at the tip and

F_f is frictional force on the disc

$$F_f = \mu\ F_N \qquad \text{.........}4$$

μ is coefficient of friction below 0.2, metal sliding against metal at high speed.[20]

Take μ =0.2 and F_N=100N, maximumcontact force between pantograph and contact wire from Addis Ababa LRT

From equation 4 , Ff = 20 N

By substituting the above values in equation 3, T=2Nm or 2000Nmm

By substituting the above values in equation 2, the power of motor

P=0.88874 kW

And the motor chosen should be greater than 0.88874kw.

But in dc motor the power calculated by P=IV in watt, I is current and V is voltage. The current and voltage can vary to get the specified power. Because of unavailability of motor in the market, for this thesis 24V and 1.2A Dc motor is used by decreasing the applied load to below 11N.

3.5. Design of Shaft

A shaft is a rotating member, usually of circular cross section, used to transmit power or motion from one place to another and is subject to torsion, bending, and occasionally axial loading. For this design of machine the shaft is subjected for axial loading.

Let's consider straight shaft connected with disc by key and with base support by bearing

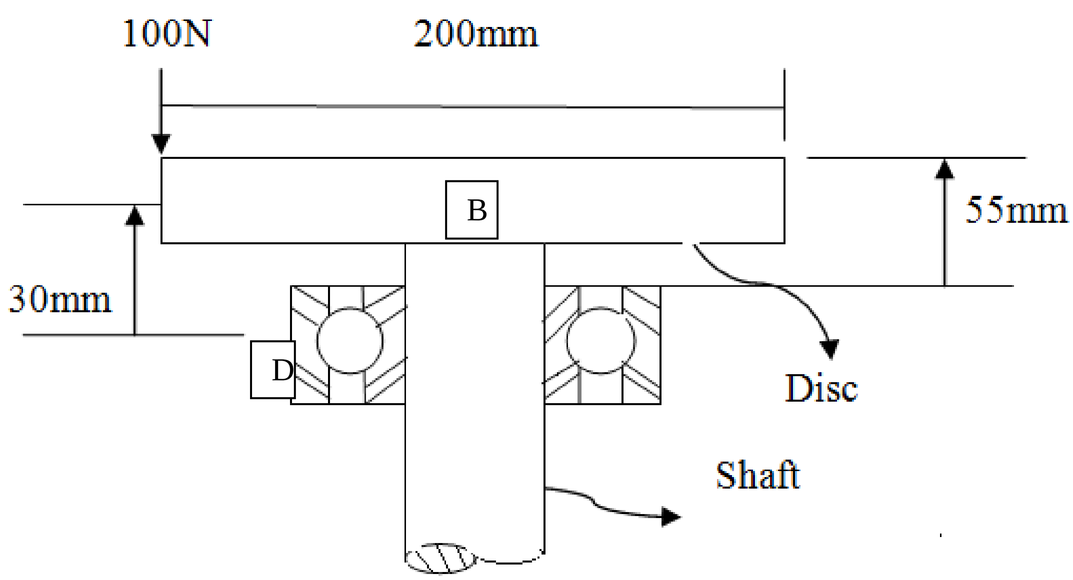
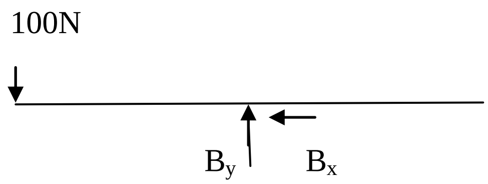
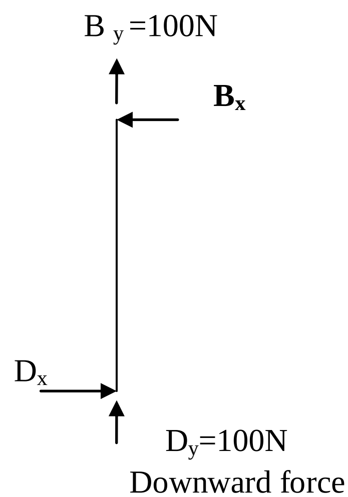


Figure 7: components on shaft

FBD of disc



FBD of shaft



To find B_y and D_y take summation of force in the X and Y axis:

Summation of all forces in the x- direction:

From FBD of disc $\sum F_x=0$

$B_x=0$

From FBD of shaft $D_x=0$

Summation of all forces in the y- direction:

From FBD of disc $\sum F_y=0$,From FBD of shaft $\sum F_y=0$

$-100N+B_y=0$ $100N+D_y=0$

$B_y=100N$ $D_y= 100N$ downward force

To find shaft diameter, use axial stress formula [25] because the shaft expose for axial load

$$\sigma a = \frac{Fa}{A} = \frac{4\alpha Fa}{\pi do^2(1-c^2)} \qquad \text{.......5}$$

Where,

F_a=axial force (tensile or compressive), from the above value the forces are tensile

C=the end condition number, for this condition C=1/4 because one end is fixed (prevented from rotation and lateral movement) and the other is free

α =Column action factor (=1.0 for tensile load)

α = arises due to the phenomenon of buckling of long of long slender members which are acted up on by axial compressive loads

Material used for shaft is 1002A[b] carbon and alloy steels with σ_u =290Mpa and σ_y =131Mpa due to [26]

- High strength
- Good machinability
- Good heat treatment property
- High wear resistance property

The allowable stress σ_{all} is the maximum stress to which a component is designed and it is much less than the ultimate stress of the material and stress by load [27]

F.S=1.6

$$\sigma_{all} = \frac{\sigma_y}{\text{F.S}} \quad \ldots\ldots 6$$

$$\sigma_{all} = 81.88mpa$$

, the tensile stress or stress by load

$$\sigma_t = \frac{\sigma_{all}}{\text{F.S}} = 51.2mpa\text{(axial stress)} \quad \ldots\ldots 7$$

Outer diameter of the shaft (d_o), from equation 5

$d_o{}^2 = \frac{4\alpha Fa}{\pi\sigma_a(1-c^2)}$, d_o=1.63mm, this shows the force applied is very small

∴ The load 100N can support by 1.63mm diameter of shaft, i.e. greater than 1.63mm shaft can support o100N force, means shaft is safe. And we can modify the shape of the shaft depend on the condition (bearing size and other part dimension), safety and for good visualization of parts. i.e. we have stepped shaft

$$let's\ take\ do = 25mm\ for\ bearing, 20mm\ to\ couple\ with\ disc, 32mm\ to\ support\ disc, 18mm\ to\ couple\ with\ motor$$

Check the stress of shaft by Ansys software and it is safe by comparing with its allowable and yield stress. See the figure 8 and 9

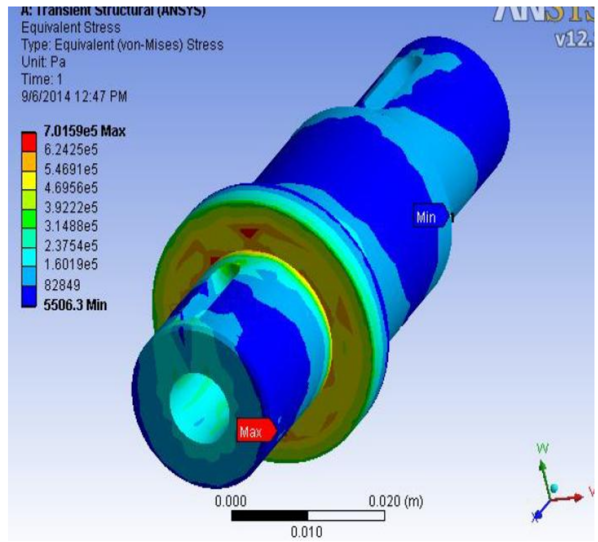


Figure 8: shaft after manufacturing process and Figure 9: Equivalent Stress on shaft

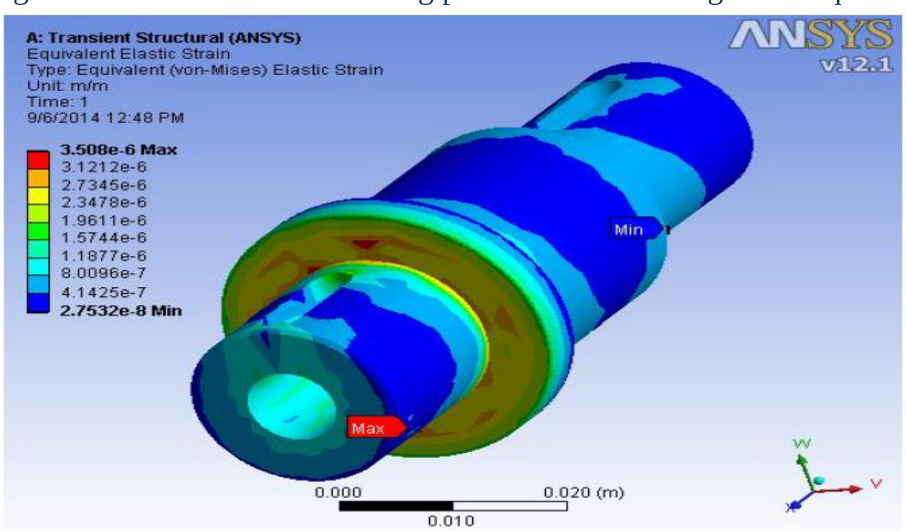


Figure 10: Equivalent elastic strain on shaft

3.6. Bearing Selection

A bearing is a device to allow constrained relative motion between two or more parts, typically rotation or linear movement. Bearings are manufactured to take pure radial loads, pure thrust loads, or a combination of the two kinds of loads. The nomenclature of a ball bearing is illustrated in Fig. 10, which also shows the four essential parts of a bearing. These are the outer ring, the inner ring, the balls or rolling elements, and the separator. In low-priced bearings, the separator is sometimes omitted, but it has the important function of separating the elements so that rubbing contact will not occur [23].

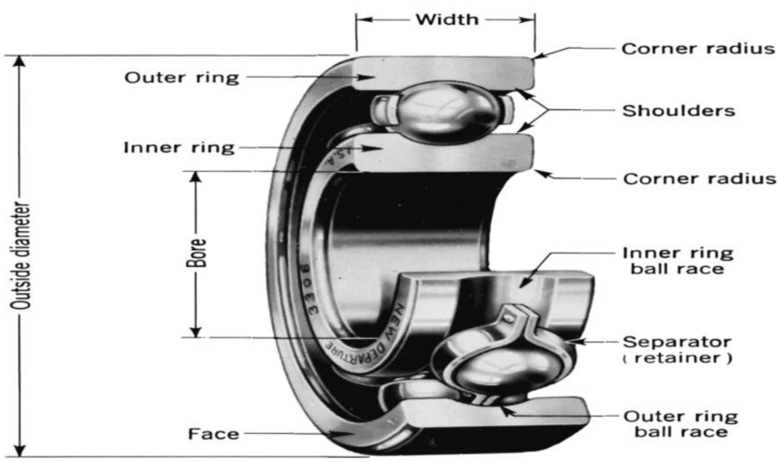


Figure 11: Nomenclature of a ball bearing [23]

Table 3: Dimensions and Load Ratings for Single-Row 02-Series Deep-Groove and Angular Contact Ball Bearings [23]

Bore, mm	OD, mm	Width, mm	Fillet Radius, mm	Shoulder Diameter, mm d_S	d_H	Load Ratings, kN Deep Groove C_{10}	C_0	Angular Contact C_{10}	C_0
10	30	9	0.6	12.5	27	5.07	2.24	4.94	2.12
12	32	10	0.6	14.5	28	6.89	3.10	7.02	3.05
15	35	11	0.6	17.5	31	7.80	3.55	8.06	3.65
17	40	12	0.6	19.5	34	9.56	4.50	9.95	4.75
20	47	14	1.0	25	41	12.7	6.20	13.3	6.55
25	52	15	1.0	30	47	14.0	6.95	14.8	7.65
30	62	16	1.0	35	55	19.5	10.0	20.3	11.0
35	72	17	1.0	41	65	25.5	13.7	27.0	15.0
40	80	18	1.0	46	72	30.7	16.6	31.9	18.6
45	85	19	1.0	52	77	33.2	18.6	35.8	21.2
50	90	20	1.0	56	82	35.1	19.6	37.7	22.8
55	100	21	1.5	63	90	43.6	25.0	46.2	28.5
60	110	22	1.5	70	99	47.5	28.0	55.9	35.5
65	120	23	1.5	74	109	55.9	34.0	63.7	41.5
70	125	24	1.5	79	114	61.8	37.5	68.9	45.5
75	130	25	1.5	86	119	66.3	40.5	71.5	49.0
80	140	26	2.0	93	127	70.2	45.0	80.6	55.0
85	150	28	2.0	99	136	83.2	53.0	90.4	63.0
90	160	30	2.0	104	146	95.6	62.0	106	73.5
95	170	32	2.0	110	156	108	69.5	121	85.0

From standard table

Ball bearing for do = 25mm

Bore=25mm

OD=52mm

Fillet radius=1mm

Width=15mm

Shoulder diameter=d_s=30, d_H =47

Load rating, KN

Deep grove=c_{10}=14, c_0=6.95

Angular contact=c_{10}=14.8, c_0=7.65

But, for this machine Bore=25mm and OD=47mm bearing and Bore=47mm and OD=52mm bronze bushing are used because of bearing house rigidity.

3.7. Key selection

Keys are used on shafts to secure rotating elements, such as gears, pulleys, or other wheels. Keys are used to enable the transmission of torque from the shaft to the shaft-supported element. For this thesis, because of manufacturing capacity rectangular with filleted end keys are used [23].

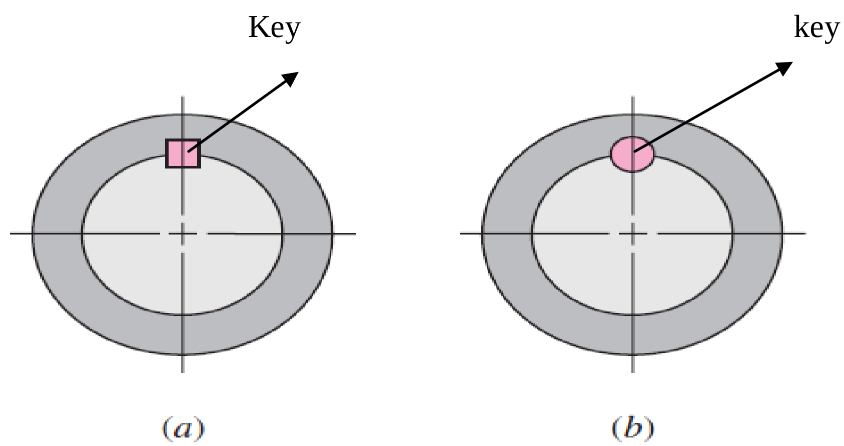


Figure 12 :(a) square key (b) round key

Table 4: Inch Dimensions for Some Standard Square and Rectangular-Key Applications [23]

Shaft Diameter		Key Size		
Over	**To (Incl.)**	**w**	**h**	**Keyway Depth**
5/16	7/16	3/32	3/32	3/64
7/16	9/16	1/8	3/32	3/64
		1/8	1/8	1/16
9/16	7/8	3/16	1/8	1/16
		3/16	3/16	3/32
7/8	1 1/4	1/4	3/16	3/32
		1/4	1/4	1/8
1 1/4	1 3/8	5/16	1/4	1/8
		5/16	5/16	5/32
1 3/8	1 3/4	3/8	1/4	1/8
		3/8	3/8	3/16
1 3/4	2 1/4	1/2	3/8	3/16
		1/2	1/2	1/4
2 1/4	2 3/4	5/8	7/16	7/32
		5/8	5/8	5/16
2 3/4	3 1/4	3/4	1/2	1/4
		3/4	3/4	3/8

The key size depend on shaft

From table

Standard key for shaft do = 18mm = 0.70866inch and do = 20mm = 0.7874inch lay in the range of 9/16-7/8 inch

Shaft diameter		key size		keyway
Over	to (inch)	W	h	depth
9/16	7/8	3/16	1/8	1/16
		3/16	3/ 16	3/32

Key material is typically made from low carbon cold-rolled steel, mostly suggested the key material to have low strength than other components in the machine (shaft, wheel, gear, etc.) for the safety of the components.

3.8. Design of compression spring

There are four types of ends generally used for compression springs. (a) Plain end, (b) Squared or closed end, (c) Squared and ground end, (d) Plain end, ground. Springs should always be both squared and ground for important applications, because a better transfer of the load is obtained. But in this case both ends plain and ground compression spring is used by manufacturing scarcity.

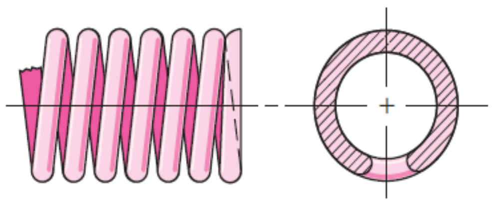


Figure 13: Compression springs: both ends plain and ground.

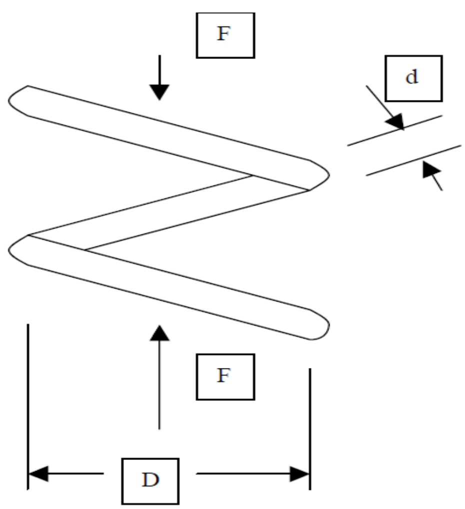


Figure 14: Nomenclature of Compression springs

Table 5: Formulas for the Dimensional Characteristics of Compression-Springs.
(Na = Number of Active Coils)[23]

Term	Type of Spring Ends: Plain	Plain and Ground	Squared or Closed	Squared and Ground
End coils, N_e	0	1	2	2
Total coils, N_t	N_a	$N_a + 1$	$N_a + 2$	$N_a + 2$
Free length, L_0	$pN_a + d$	$p(N_a + 1)$	$pN_a + 3d$	$pN_a + 2d$
Solid length, L_s	$d(N_t + 1)$	dN_t	$d(N_t + 1)$	dN_t
Pitch, p	$(L_0 - d)/N_a$	$L_0/(N_a + 1)$	$(L_0 - 3d)/N_a$	$(L_0 - 2d)/N_a$

Let us start with a trial wire diameter D_w=2mm and check by an acceptable spring index C, C should be 5≤C≤12 are preferred for plain and ground end compression springs.

$$C = D_m / D_w \quad \text{..8,}$$

Where

D_m is mean diameter and D_w is wire diameter

D (diameter of the coil) =13mm, equal to pin diameter)

D_i is internal coil diameter = D – D_w =11

$$D_m = \frac{D+Di}{2} = 12\text{mm}$$

From equation 8, $C = D_m / D_w$ =12/2=6, it is safe.

Required: pitch, P

$$P = (L_o - 2Dw)/N_a \quad \text{……………………………………9,}$$

Where

N_a is the number of active turns, in determining this account must be taken of the ways that the end of the coil are finished and appropriate corrections made

In addition to the relationships and material properties for springs, we now have some recommended design conditions to follow, namely:

$5 \leq C \leq 12$

$3 \leq Na \leq 15$, the range C and Na from [23]

Let's guess or take N_a =8 appropriate with free length

And free length L_o =28.5 mm

By substituting the above value in equation 9, P=3.0625mm

Total coil number, Nt =Na+2=10

Solid height = $D_w N_a + 2 D_w$=20mm

The stiffness of the spring (k) in terms of its geometry and shear modulus G and number of active coil Na,

$$k = \frac{GDw^4}{8D^3N_a} \text{..................................} 10$$

Where

G is the shear modulus, for spring steel a value of 80Gpa can be used

D_w is wire diameter

Substitute the values in equation 10 and K=9.1N/mm

Spring obey hook's law when used in static application

$$F=K\Delta L \text{..................................} 11$$

Where

F is uplifting force of pantograph of Ethiopian light rail transit (90±10), take maximum 100N

L is the deflection,

K is Stiffness of the spring

By substituting the value in equation 11, L=10.99mm

For this research the force applied by the bolt, it has spring inside

For the designed bolt, 1 pitch =1.5mm

For L=10.99mm, there is 7.33pitch (if needed to apply 100N force in the pin, can rotate the indicator by 7.33pitch or 7.33 revolution because 1rev=1pitch)

Therefore, to get the deflection of any applied force, the above stiffness and the needed force can be used.

Material for spring: AISI 1086 or CSN 12090 may be used in the hardened and tempered condition or cold drawn for diameter up to 12mm.and the designed material hardened by 800 ^{0}c and tempered by 400 ^{0}c.

Checking of spring for Shear [23]

A compression spring with plain ends using hard –drawn wire

The shear stress

$$\tau_{max}=\frac{k_B 8 F_{max} C}{\pi\, d^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 12$$

Where

k_B is a factor =4C+2 /4C-3=1.263

F_{max}=maximum applied force=100N

C=spring index=from the above getting value, 5.5

D =diameter of wire=2mm

Substitute the above values in equation 12 and τ_{max} =442.228N/mm^2 , 1GPa=1000N/mm^2

τ_{max}= 0.442228GPa

τ_{max}< G(shear modulus of the material=80GPa),

Can conclude the spring material is safe.

Checking of spring for Stability [23]

Compression coil springs may buckle when the deflection becomes too large.

Table 6: End-Condition Constants α for Helical Compression Springs[23]

End Condition	Constant α
Spring supported between flat parallel surfaces (fixed ends)	0.5
One end supported by flat surface perpendicular to spring axis (fixed); other end pivoted (hinged)	0.707
Both ends pivoted (hinged)	1
One end clamped; other end free	2

For steels, this turns out to be

$$Lo < 2.63\frac{D}{\alpha} \quad \ldots\ldots 13$$

Calculate α to check the spring expose for buckling

Spring has fixed ends

From equation 13, the constant $\alpha < 2.63D/Lo$, for Lo=28.5mm and D=13mm

$\alpha < 1.199$

From above Table, the spring is stable provided it is supported between either fixed-fixed or fixed-hinged or both ends hinged ends.

The final results are:

$D_w = 2mm$

Outside coil diameter: OD = 13mm

Total number of coils: Nt = 10 turns with plain ends

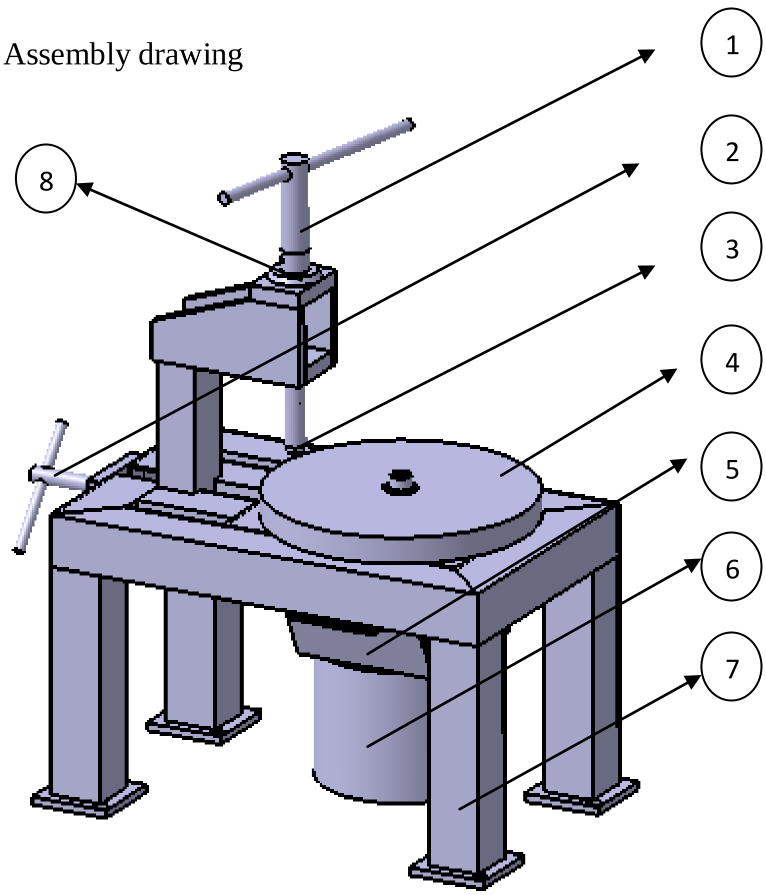
Free length: L0 = 28.5mm

Pitch, P=3.0625mm

3.9. Main frame

For frames , SHS material are chosen to support any high load, the dimensions are mentioned in working drawing and the rest standard part component of pin on disc tribometer machine dimensions also mentioned.

Assembly drawing



Overall dimension

Length=346mm,

Width=211mm, height=450mm

No.	Part name (main component)
1	T –bolt (pin holder)
2	T –bolt(direction adjuster)
3	Pin
4	Disc
5	Motor Support
6	Motor
7	Supporter(frame)
8	Pitch guage

Figure 15: model of pin on disc tribometer machine by Catia v5

Figure 16: photo of tribometer machine in METECH

CHAPTER FOUR: EXPERIMENTAL METHODS AND CONDITION

4.1. Test Specimen Materials

Preparation for melting samples (pin)

1. Collecting material

For this research the industrial grade materials are taken from manufacturing industries and consider the impurities like as amount of iron in the material. For example to get pure silicon, 45%FeSi (45% silicon in FeSi) have been collect, then calculate amount of pure silicon to add in the composition to be melt.

.

Figure 17: the raw material of pins

2. Amount preparation

After getting the material to get the needed percentage composition, calculation was needed.

To get the below composition

Table 7: pin material composition with impurities

Material	Chemical composition in %				
	Cu	Ni	Si	Cr	Impurities
Cu	99.8% with 0.04%O_2				<0.16
CuNiSiCr	96.3 With 0.04%O_2	0.94	0.19	0.003	<2.527
CuAg	By ERC specification(0.08-0.12% of Ag)				

First calculate the gram of dia.13 xlength13mm of one pin

Area of pin

$A = \pi d^2/4$, A=132.73mm^2

Volume of pin

$v = A\ x\ l$, L is length of pin, v=1.72552 cm^3

Mass of pin

$\rho = \frac{m}{v}$, $m = \rho v$, ρ *is density of copper* 8.96 g/cm^3 , m=15.461 gram

Then consider 100% copper is equal to 15.461 gram of copper and calculate each element percentage out of 100%.

For example

Calculate the gram of 0.94% of nickel out of 100 %(15.461 gram) of copper alloy

$\frac{0.94\%}{100\%} = \frac{x}{15.461\ \text{gram}}$, x =0.1453334 gram of nickel is needed to melt one pin

If we need more pins, multiply the gram by number of pins. Other amount of elements was calculated in the same manner.

3. Melting process

After amount preparation the melting process was performed by oil furnace at yalew garage around kadisco, saris.

Table 8: Melting temperature of materials

Material	Melting point in ^{0}c
Copper	1083
Nickel	1452
Chromium	1890
Silicon	1430

First melt the base metal of the composition copper, and then add others first chromium, second nickel, third silicon by descending order of their melting point. Mostly experienced persons can know the temperature of furnace simply by observation, but in practice we can know by infrared instrument. After melting pour the alloy immediately in hollow cylindrical steel mold, then cooled by air or use water as quenching media. Finally machining process followed to get the necessary shape mentioned in the above.

Figure 18: furnace room

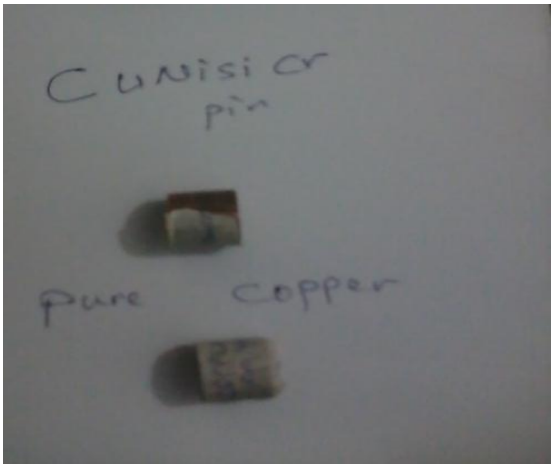


Figure 19: The melted copper and alloy

After melting process

In order to know the chemical composition of the specimen, the spectrometer machine is used and the average result taken after three tests

Table 9: chemical composition of copper alloy and disc

Material	Chemical composition in %					
	Cu	Ni	Si	Cr	Ag	Impurities
Cu	99.8% with 0.04%O_2					<0.16
CuNiSiCr	96.3 With 0.04%O_2	0.94	0.19	0.003	-	<2.527
CuAg	99.3	-	-	-	0.08	<0.62

Material (disc)	Composition in %							
	C	Si	Mn	P	S	Ni	Cr	Mo
Stainless steel(316L)	0.08	1	2	0.045	0.030	10-14	16-18	2-3

Table 10: The hardness, Surface roughness and conductivity value of pins and discs

Material	Value of			
	Hardness (Hv)	Density (g/cm3)	Electrical Conductivity (% IACS)	Surface roughness Ra(μm)
Pin	before test			
Pure copper	72	8.90	100	1.128
Cu Ni Si Cr alloy	131.3	8.84	29	1.486
Cu Ag	168	7.4	98.70	2.2423
Disc				
Stainless steel (AISI 316L)	151	7800kg/m3	-	-

Remark: The strengthening of the Cu–Ag alloy has been reported in [15].

Pure copper and Cu Ni Si Cr alloy in [4].

Cost of materials from the market

The cost taken before six month from Micron international trading house PLC and let's compare the three compositions

Table 11: cost of each material

Cu	Cu =680 birr/500 gram
Cu Ag	Cu =680 birr/500 gram; Ag=70birr/1gram
Cu Ni Si Cr	Cu =680 birr/500 gram; Ni=460birr/500gram; Si=600birr/100gram; Cr=450birr/100gram

Let's compare the cost per one pin
One pin = 15.461gram

For pure copper in one pin (Cu =99.8%)
99.8/100=x/15.461gram, x=15.43gram; i.e. there is 15.43gram of cu in 15.461gram of pin
Check the cost
680birr/500gram
Therefore, y/15.43gram=680 birr/500gram, **y=20.985birr for 99.8%cu in one pin**

For Cu Ag (Cu=99.3%, Ag=0.08%)
For copper 99.3/100= x/15.461, x=15.353gram
Y/15.353gram= 680 birr/500gram, y=20.88birr for 99.3%cu in one pin
For Ag 0.08/100=x/15.461gram, x=0.0124gram
y/0.0124gram=70birr/1gram, y=0.868birr for 0.08%Ag in one pin

Total cost for Cu Ag per pin
=20.88birr+0.868birr
=21.748birr for one pin of Cu Ag

For Cu Ni Si Cr (Cu=96.3%, Ni=0.94%, Si=0.19%, Cr=0.003%)
For copper
96.3/100=x/15.461gram, x=14.889gram
y/14.889gram=680birr/500gram,y=20.25birr for 96.3% Cu in one pin
For nickel
0.94/100=x/15.461gram, x=0.145gram
y/0.145gram=460birr/500gram, y=0.1334birr for 0.94%Ni in one pin
For silicon
0.19/100=x/15.461gram, x=0.0294gram
y/0.0294gram=600birr/100gram, y=0.1764birr for 0.19% Si in one pin
For chromium
0.003/100=x/15.461gram, x=4.6383E-04gram
y/4.6383E-04=450birr/100gram, y=2.087E-03 birr for 0.003%Cr in one pin
Total cost for Cu Ni Si Cr per pin
=20.25birr+0.1334birr+0.1764birr+2.087E-03 birr
=20.562birr for Cu Ni Si Cr in one pin

Let's compare the three material cost
Cu =20.985 birr
Cu Ag=21.748birr
Cu Ni Si Cr=20.562 birr
Therefore, the Cu Ni Si Cr copper alloy takes less cost from others.

4.2. Dimension

To compare the pure copper and alloy materials results , the cu, Cu Ni Si Cr, and Cu Ag alloy pins are prepared by 13mm diameter and 13mm length, this size adapted from actual contact wire size. And the material has chosen by the consideration of their good wear and corrosion resistance properties.

And stainless steel disc (316L) of 200mm diameter will prepare, this size taken to have different wear truck and the material chosen by consideration of copper alloy have to test by great hardened material (i.e. the alloys will perfect for carbon brush and other material).

4.3. Experimental Procedure and Condition

For wear

- The two copper alloys Cu Ni Si Cr , Cu Ag and pure copper will selects
- Manufacture the pin alloys and pure copper of diameter of 13mm and length of 13mm and 200mm diameter stainless steel disc using manufacturing process.
- Check the hardness and material composition using hardness and spectrometer respectively, before test.
- Weight the specimen by electronic balance
- Then, the wear test conduct using pin-on-disc tribometer by copper alloy pins are force to slide against stainless steel disc driven by an electric motor in work shop temperature of air unlubricated condition at constant sliding speed of 80 km/hr the hardness of stainless disc is 151 HV.
- Normal forces of 5, 7.86, 10.24N and dc current intensity 0A will apply during the test. The motor connected to the power supply to rotate the motor
- The test duration was one minutes and the weight loss Δw (in gram) of the specimen in wear time t (in minute) was recorded by an electronic balance. The volume loss Δv (in mm^3) was calculated by the following equations:
  - ✓ $\Delta v = 1000\Delta w/\boldsymbol{\rho}$; Where **ρ** is the density of the alloys in g/cm^3.
  - ✓ The wear rate w (in mm^3/h) and wear resistance R (in h / $mm^{3)}$ are defined as:
    - ✓ $W=\Delta v/t$ and $R=1/w$
- The worn surface and wear debris of the selected specimen will characterize by metallurgical microscopy
- Finally put the conclusion about the materials by comparing each others

For corrosion

The arm field corrosion studies kit uses a number of simple items of equipment in a series of tests, designed to demonstrate to the student how potentially corrosive situations may be recognized and avoided. Although the experiments refer principally to steel-water systems, the apparatus may be used as a test bench for other chemical system [19].

Figure 20: specimen in corrosion studies kit

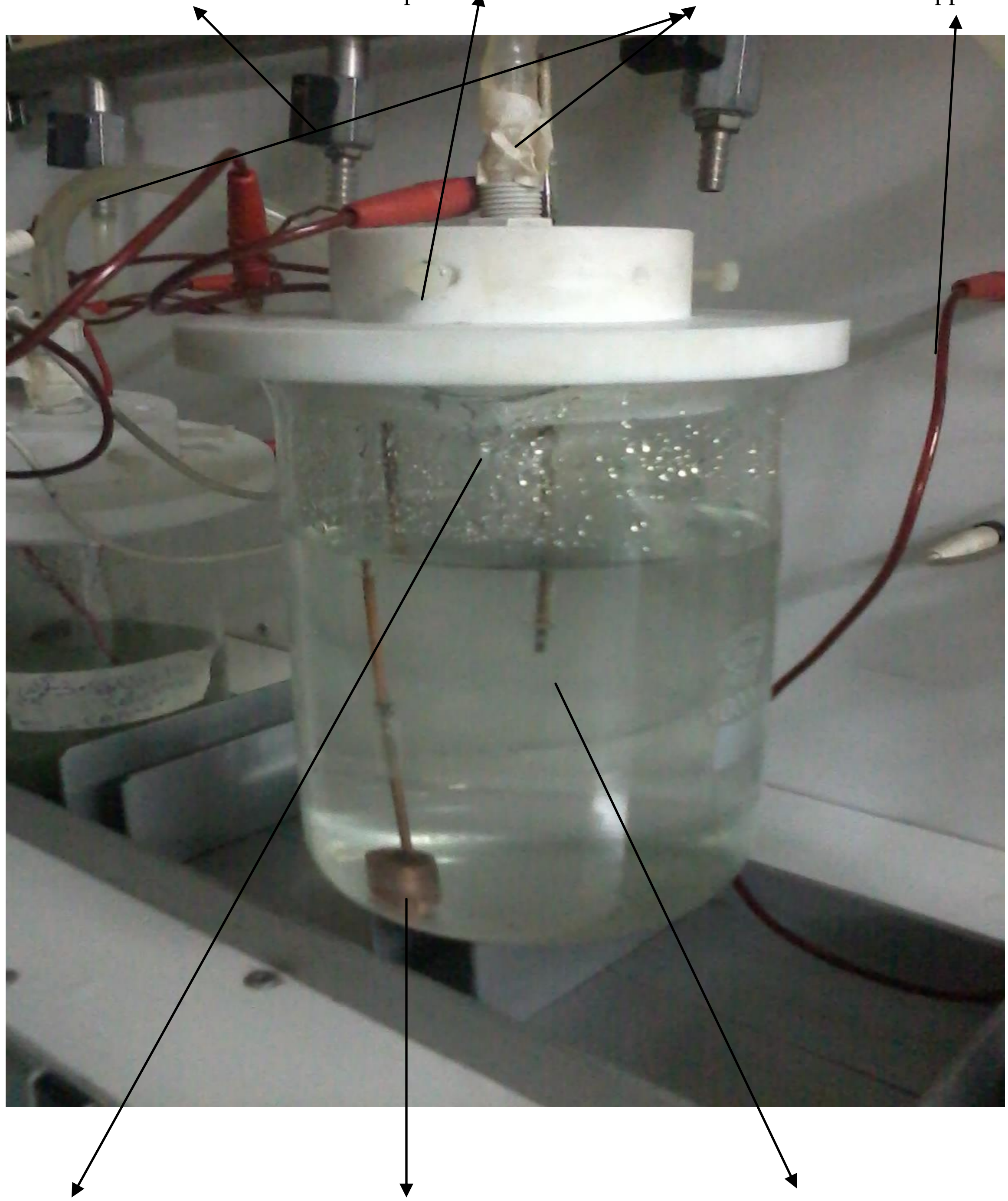


Figure 21: Vickers with Nacl solution

Figure 22: ph value and acid adding process

Figure 23: specimen in the warm oven and cooling process

Corrosion test

After knowing the composition the corrosion test was conducted and the corrosion resistance is calculated by gram loss that tried to show on the above figures

Procedure for corrosion test

- Wash the specimen by 100ml distilled water and 0.5 hydrochloric acid (Hcl) for 15 minutes in order to remove corrosion initiators compound
- Dry the specimen thoroughly in warm oven at maximum temperature of 70 ^{0}c
- Each sample must be weighted by electronic balance before immersed in the solution and carefully labeled to later identify their initial weight
- Fill the Vickers with proper amount of water
- Make 3.5%Nacl solution, acid rain solution with 5PH,rain water and pure distilled water for stress test in each Vickers for each specimen
- Leave the specimen for 3 to 7 days
- After the experiment has been completed, wash the specimen by HCl like before test or brush the specimen with running water and dry with warm woven and then reweighed.
- Put the gram difference which indicates the corrosion part.

CHAPTER FIVE: RESULTS AND DISCUSSIONS

5.1. Results

For corrosion

Table 12: weight loss of material after corrosion test

	material	All are with21%oxygen			
Corrosion media		3.5%Nacl	PH5 Acid rain	Rain water	stress
Gram of specimen in each media before corrosion	Cu	15.7244	17.4234	12.6748	14.5748
	CuAg	24.5663	19.7050	25.7145	23.3757
	CuNiSiCr	15.0532	14.7038	14.7664	15.1376
Gram of specimen in each media after corrosion	Cu	15.5888	16.5843	15.6294	14.3512
	CuAg	24.4632	19.0521	25.7096	23.3747
	CuNiSiCr	14.9374	14.2287	14.7622	15.0977
Weight loss after corrosion in gram	Cu	0.1356	0.8391	0.2236	0.0454
	CuAg	0.1031	0.6529	0.1049	0.031
	CuNiSiCr	0.1158	0.475	0.0399	0.0042

For wear

The data got from wear test

In wear truck radius r=70mm, time t=1min, rotational velocity w=5898rpm, linear or design speed of train=80km/hr, force applied F=5N.

Table13: wear resistance value of materials

Material	Specimen gram		weight loss Δw (in gram)
	Before test	After test	
Cu	15.5225	15.4815	0.041
Cu Ag	14.5944	14.5599	0.0345
Cu Ni Si Cr	14.7401	14.7301	0.01

For 7.68N

Material	Specimen gram		weight loss Δw (in gram)
	Before test	After test	
Cu	15.4815	15.4615	0.102
CuAg	14.5599	14.4909	0.069
Cu Ni Si Cr	14.7301	14.6841	0.046

For 10.24N

Material	Specimen gram		weight loss Δw (in gram)
	Before test	After test	
Cu	15.4615	15.3095	0.152
CuAg	14.4909	14.4109	0.08
Cu Ni Si Cr	14.6841	14.6221	0.062

Material	volume loss Δv (in mm^3) $\Delta V = 1000\Delta W/\rho$			wear rate w (in mm^3/h) $W = \Delta V/t$		
	Force applied in N					
	In 5N	7.68N	10.24N	In 5N	7.68N	10.24N
Cu	4606.7	11461	17078.7	276346.7307	687522.4955	1024517.097
Cu Ag	4662.2	9324.3	10811	279676.0648	559346.1308	648530.2939
Cu Ni Si Cr	1131.22	5203.62	7013.57	67859.62807	312154.769	420730.054

Material	wear resistance R (in h / $mm^{3)}$ $R = 1/W$		
Force applied in N	In 5N	7.68N	10.24N
Cu	3.62E-06	1.454498E-6	9.760696E-07
Cu Ag	3.576E-06	1.7878E-06	1.542E-06
Cu Ni Si Cr	1.4736E-05	3.204E-06	1.42581E-04.

5.2. Discussions

For corrosion

The corrosion test is done for five days, and the high weight loss indicate the high corrosion rate property of the material, as shown in the graph and picture below, the corrosion effect seen highly in pure copper, less in CuNiSiCr

1. **Graph of Corrosion effect**

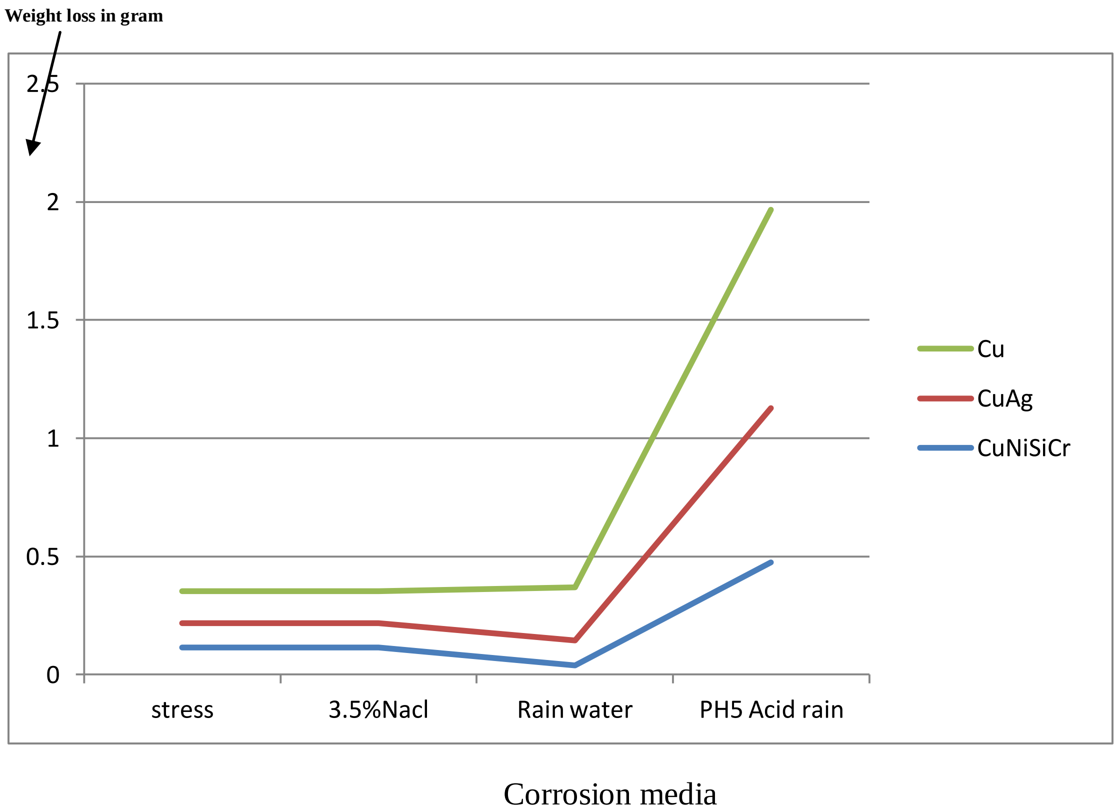


Figure24: Weight loss after five day corrosion test versus corrosion media

2. Picture of corroded specimen in each media

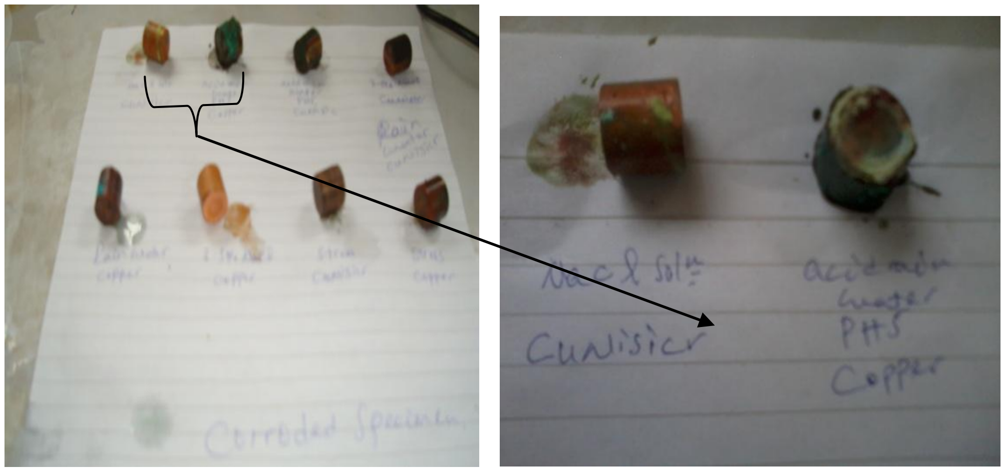


Figure 25: Corroded specimen of copper and Cu Ni Si Cr alloy

For wear

1. Introduction

Wear is the surface damage or the removal of the material from the surface of a solid body as a result of mechanical action of the counter body/sliding, rolling or impact motion/ and is generally accelerated by frictional heating (or thermal means).

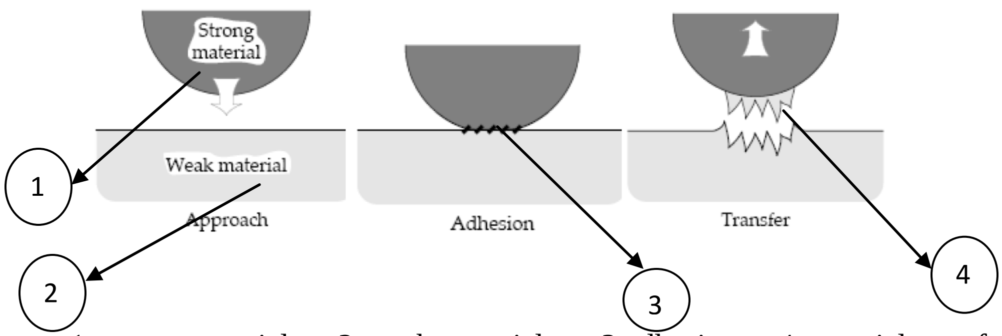
There are five different types of wear or wear mechanisms: adhesive, abrasive, fatigue, corrosive and erosive wear. In many cases, the combinations of the adhesive, corrosive abrasive forms of wear occur and wear by all mechanisms except by fatigue mechanism, occurs by gradual removal of material.

Adhesive wear occurs when two normally flat bodies are in sliding contact. The load applied is so high that adhesion (or bonding) and deformation occurs at the asperity contacts at the interface, and these contacts are sheared by sliding. The motion of the rubbing counter bodies result in rupture of the micro joints. Thus some of the material is transferred by its counter body. Strong adhesion between the asperities of wearing surfaces has two effects:

1. A large component of frictional force is generated and the asperities may be removed from the surface to form wear particles.

2. Transfer layers

Numerous tests on a wide variety of metal combinations have shown that when there is strong adhesion, transfer of the weaker metal to the stronger occurs.

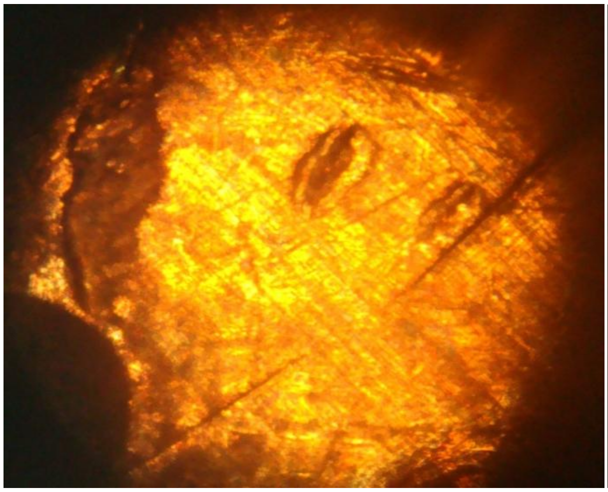
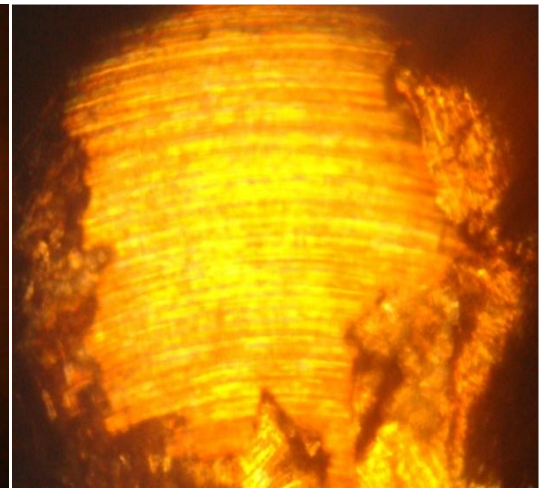


1-strong material 2-weak material 3.adhesion 4.material transfer

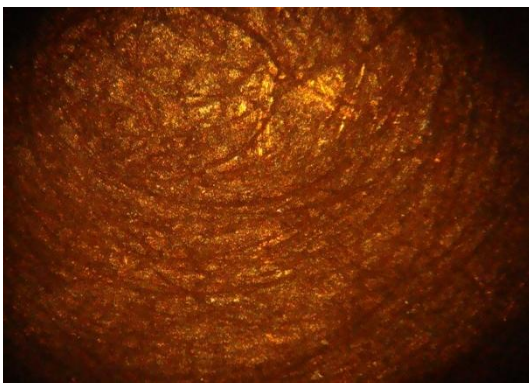
Figure 26: process of metal transfer due to adhesion

In this study based on the above explanation ,the wear occur by sliding contact of two flat surfaces and as we can show from figure 26 the material transfer from soft material copper and alloy specimen to hard material stainless steel disc. Therefore, we can conclude that the wear occurs in the specimen is adhesive wear.

2. After sliding contact of the specimen with disc or mechanical sliding wear in pin on disc tribometer machine, worn surface or macro structure of specimen with 10x100 magnification shown by metallurgical/optical microscope in mechanical workshop at Addis Ababa faculty of engineering and the worn surface in descending order Cu> Cu Ag > Cu Ni Si Cr

(a) (b)



(c)

Figure 27: worn surfaces of (a) Cu; (b) Cu Ag and (c) Cu Ni Si Cr with load 10.24N and without current and 10x100 macroscopic image by optical/metallurgical microscope

3. The below graph shows

- The wear resistance property of each material
- When the force increase the wear resistance of all material decrease because of happened high friction at the contact
- The wear resistance value of Cu Ni Si Cr is greater from others

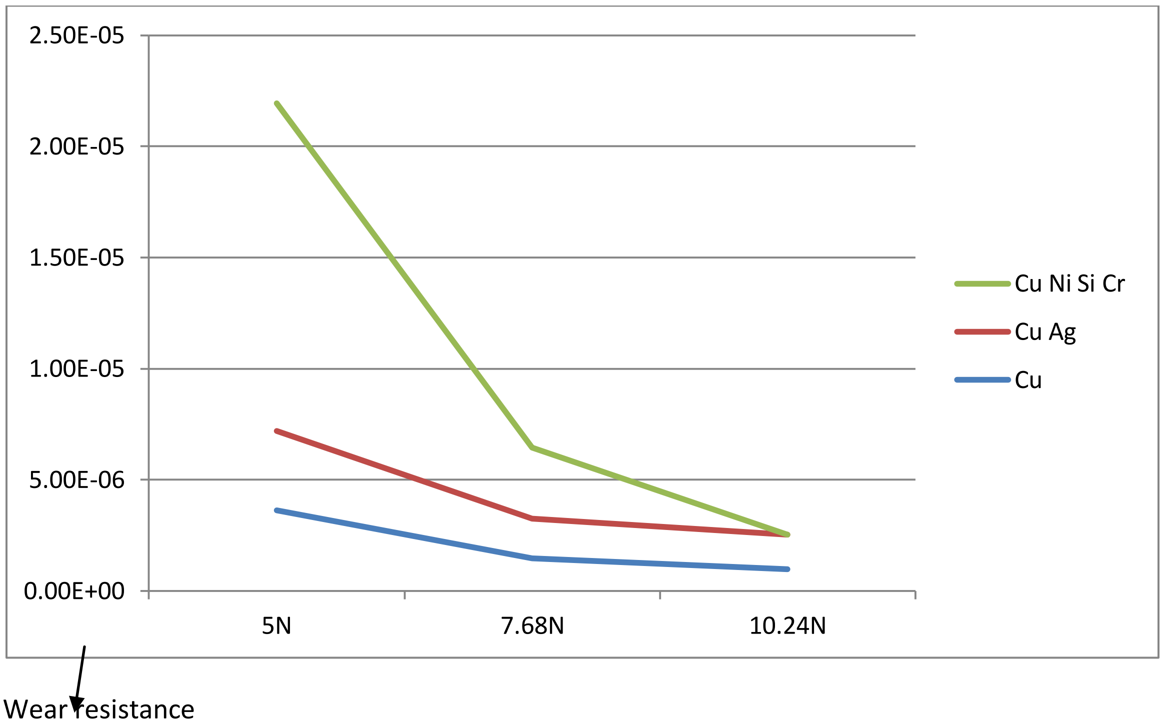


Figure 28: wear resistance of each material versus applied force

CHAPTER SIX: CONCLUSION, RECOMMENDATION AND FUTURE WORK

6.1. Conclusion

In this study, the properties of materials for train overhead line contact wire are determined under different load and environmental conditions.

Due to the experimental result, the following conclusion are made

- The Cu Ni Si Cr has greater corrosion and wear resistance property than others and also take less purchase cost
- When the normal load increase, the wear rate also increase
- High corrosion effect observed in ph5 acid rain corrosion media, i.e. harmful gases that out from industries and cars
- The dominant wear mechanism during the mechanical sliding wear processes is Adhesive wear.

6.2. Recommendation

Based on wear and corrosion resistance property and each material purchase cost, the researcher recommend the Addis Ababa light rail project to use Cu Ni Si Cr alloy for over head line contact wire by making further investigation and from ph5 acid rain corrosion media result, it is necessary to suggest for the future Addis Ababa to have protected environment beyond the contact wire material property.

6.3. Future Work

The following are recommended for future work as expansion of this research

- See the effect of sliding wear with electrical current(electromechanical wear)
- Test the corrosion without current and compare to with current

- Specify the dominant wear mechanism during the electrical sliding wear processes.(Adhesive wear, abrasive wear and electrical erosion wear)
- In the future it is better to suggest researchers to do increasing the capacity of machine by increasing the capacity of motor and variable voltage supply or inverter to increase the condition that apply on disc like force and speed.
- Create a constant electric power supply mechanism for pin (pure copper and copper alloy specimen) to do the experiment with current effect in the machine.
- Check the electrical conductivity property of Cu , Cu Ag and Cu Ni Si Cr
- See the effect of chemical composition percentage of pin material by decreasing or increasing
- Check the wear and corrosion resistance property of materials using related software

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Appendix

Calibration certificate of electronic balance

NATIONAL METROLOGY INSTITUTE OF ETHIOPIA
(NMIE)

CERTIFICATE OF CALIBRATION

This calibration certificate documents the traceability to national standards, which realize the units of measurement according to the international system of units

PO BOX 5722
Addis Ababa, Ethiopia
Tel: 251-0116517985
Fax: 251-0116459312
e-mail: info@nmie.net
website: http://www.nmie.net

Date of Issue: 2013-01-29 Certificate number: B05-2091 Page 3 of 3

Measuring results

Applied Standard load [g]	Instrument Reading [g]	Correction [g]
0	0.0000	0.0000
20	20.0002	-0.0002
40	39.9979	0.0021
60	59.9975	0.0025
80	79.9976	0.0024
100	100.0059	-0.0059
120	120.0059	-0.0059
140	140.0035	-0.0035
160	160.0028	-0.0028
180	180.0003	-0.0003

Note: Standard (Actual) value = Instrument reading + Correction

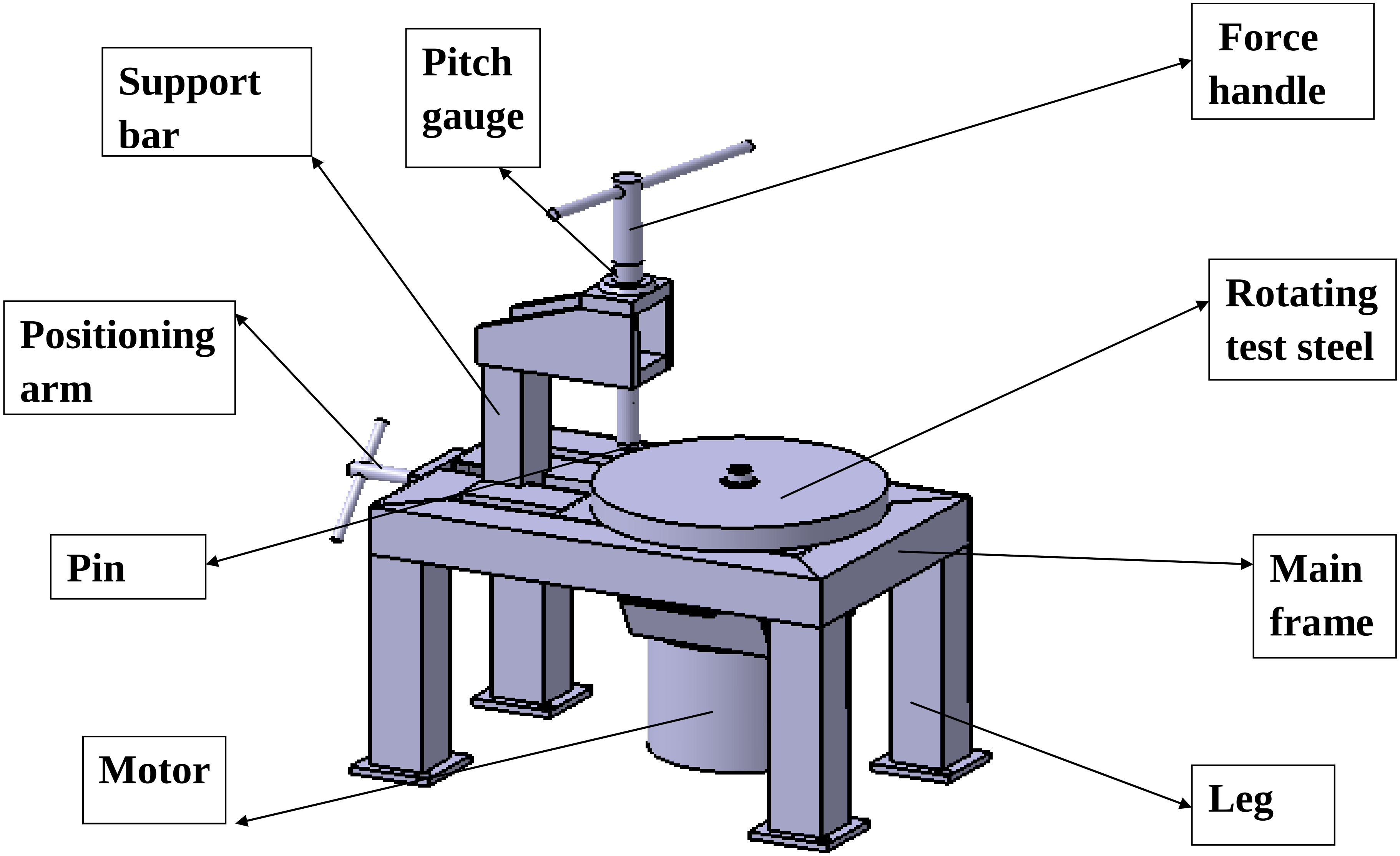
Estimated uncertainty of measurement: ± 0.005g

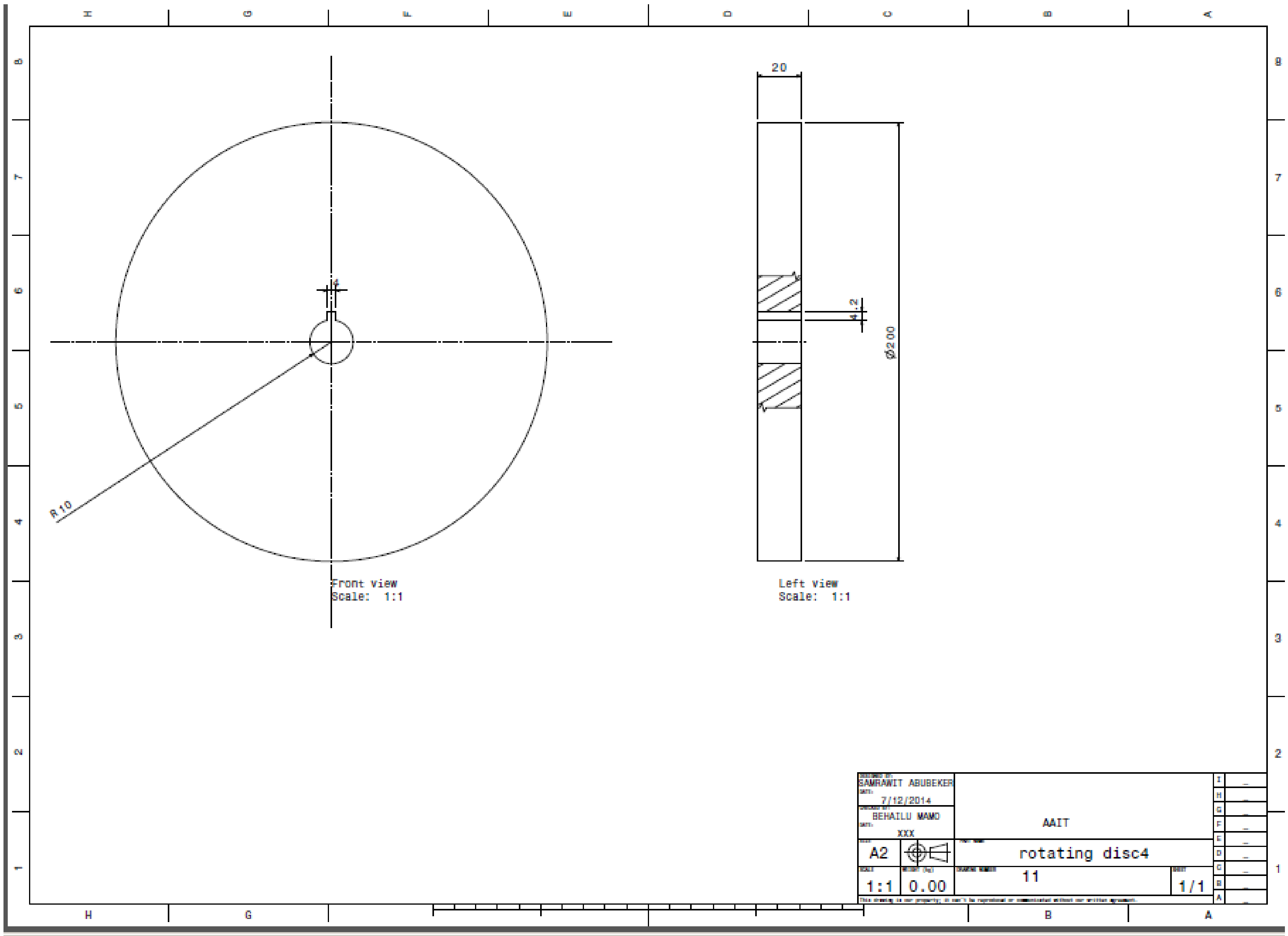
The uncertainties are based on root sum square of the contributions with a confidence interval Not less than 95% and coverage factor k=2.

End of Certificate

THE FEDERAL DEMOCRATIC REPUBLIC OF ETHIOPIA NATIONAL METROLOGY INSTITUTE

WORKING DRAWINGS OF SOME MAIN PARTS


Support bar
Pitch gauge
Force handle
Positioning arm
Rotating test steel
Pin
Main frame
Motor
Leg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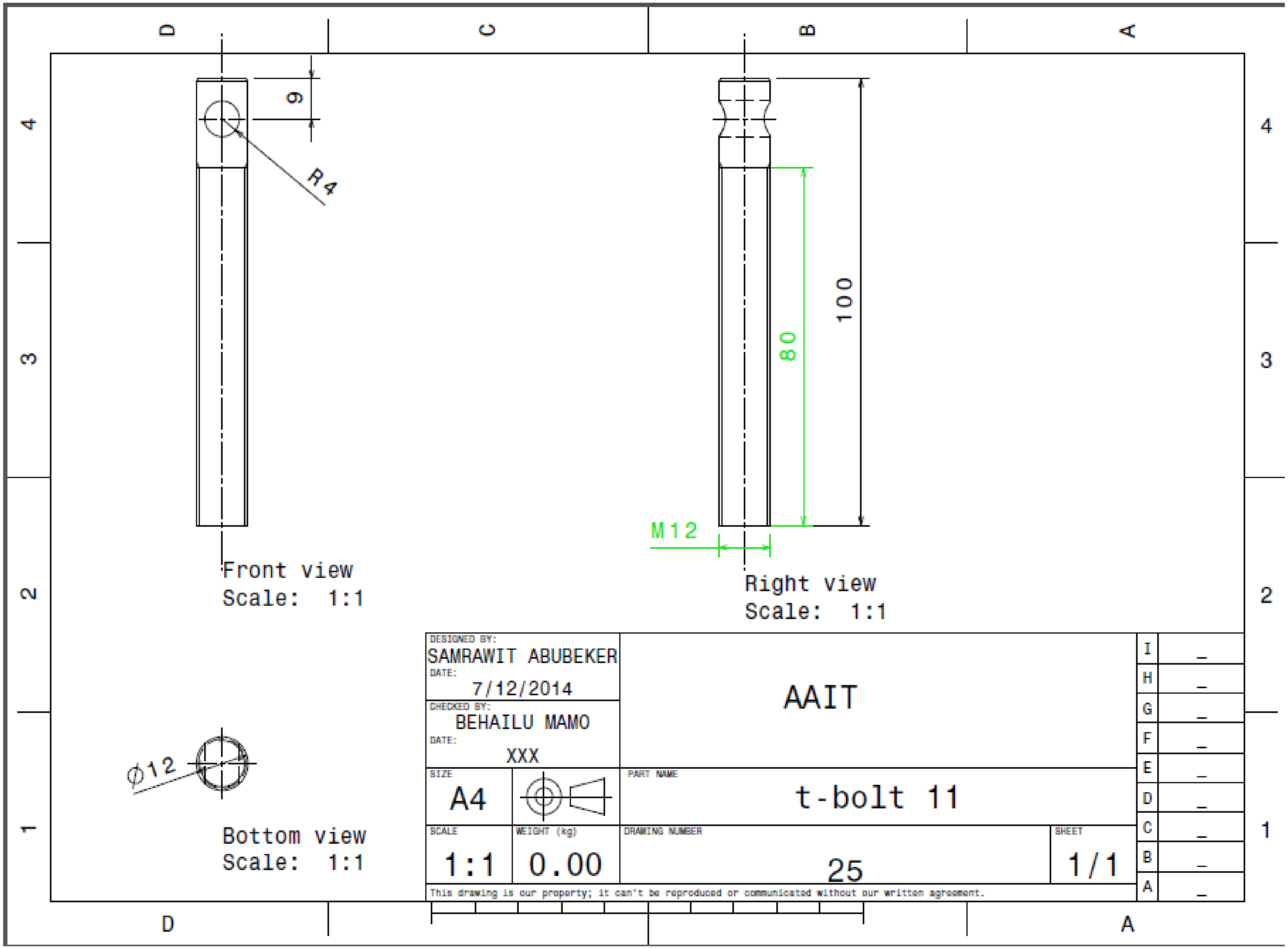
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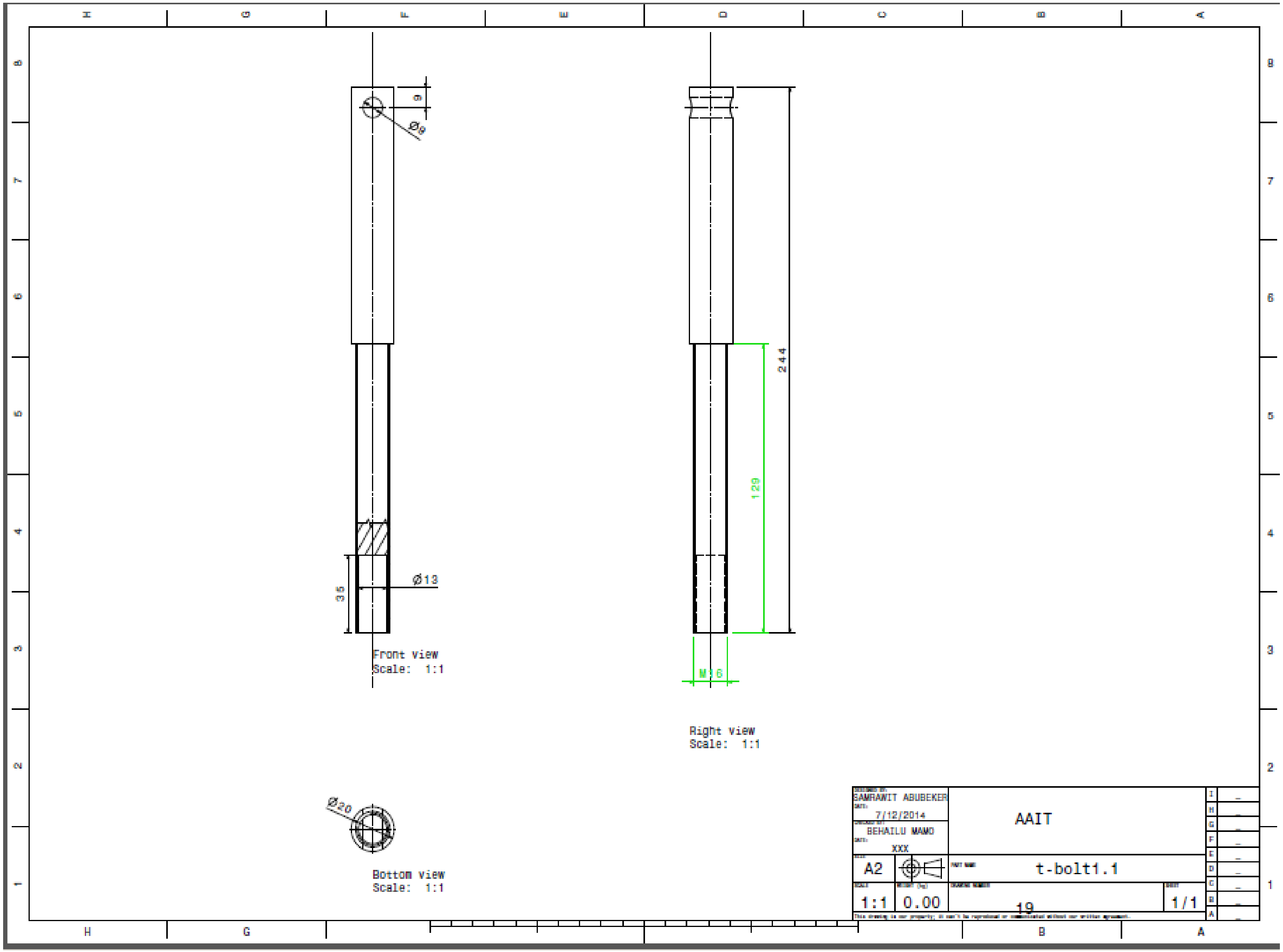

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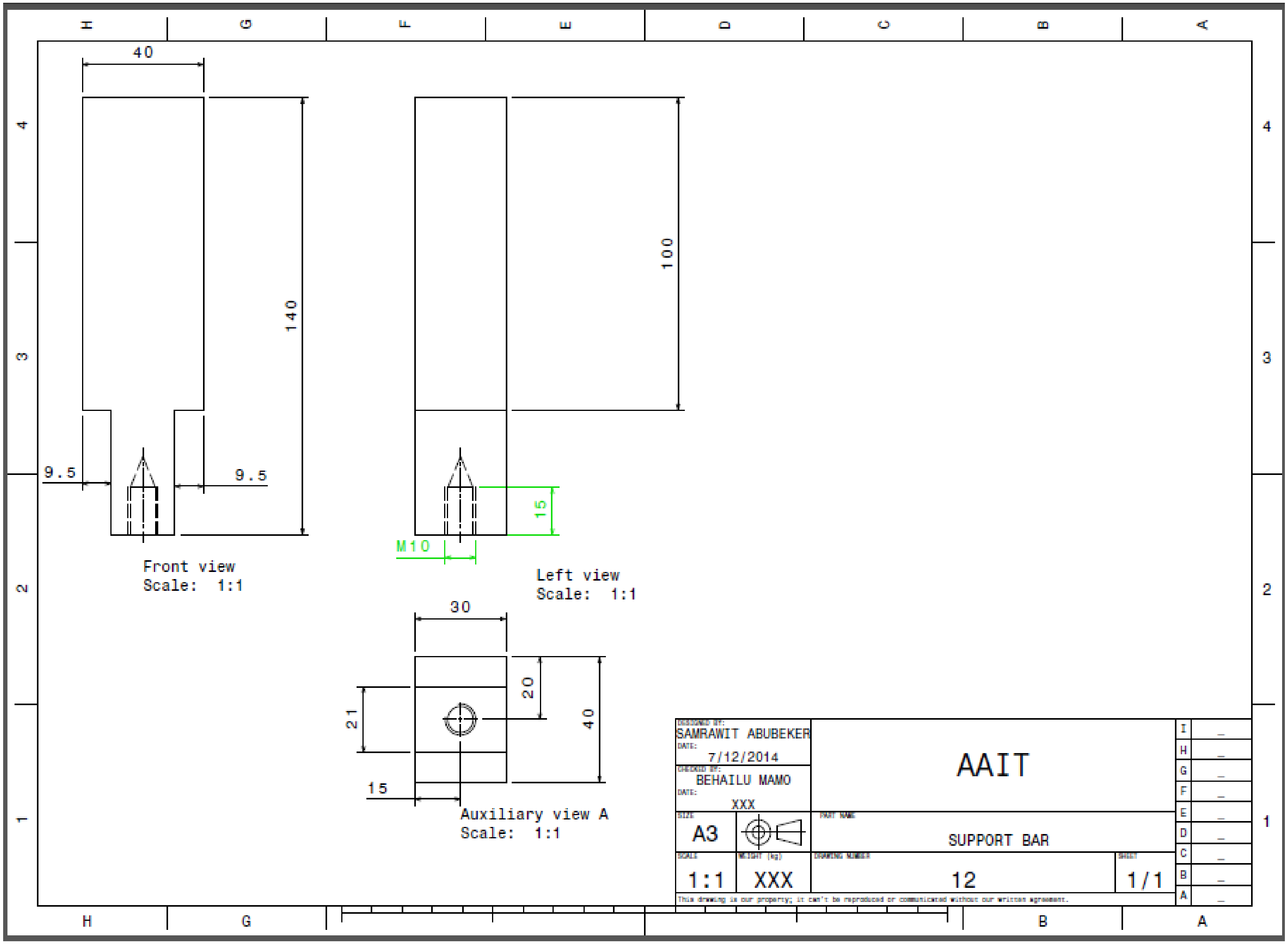

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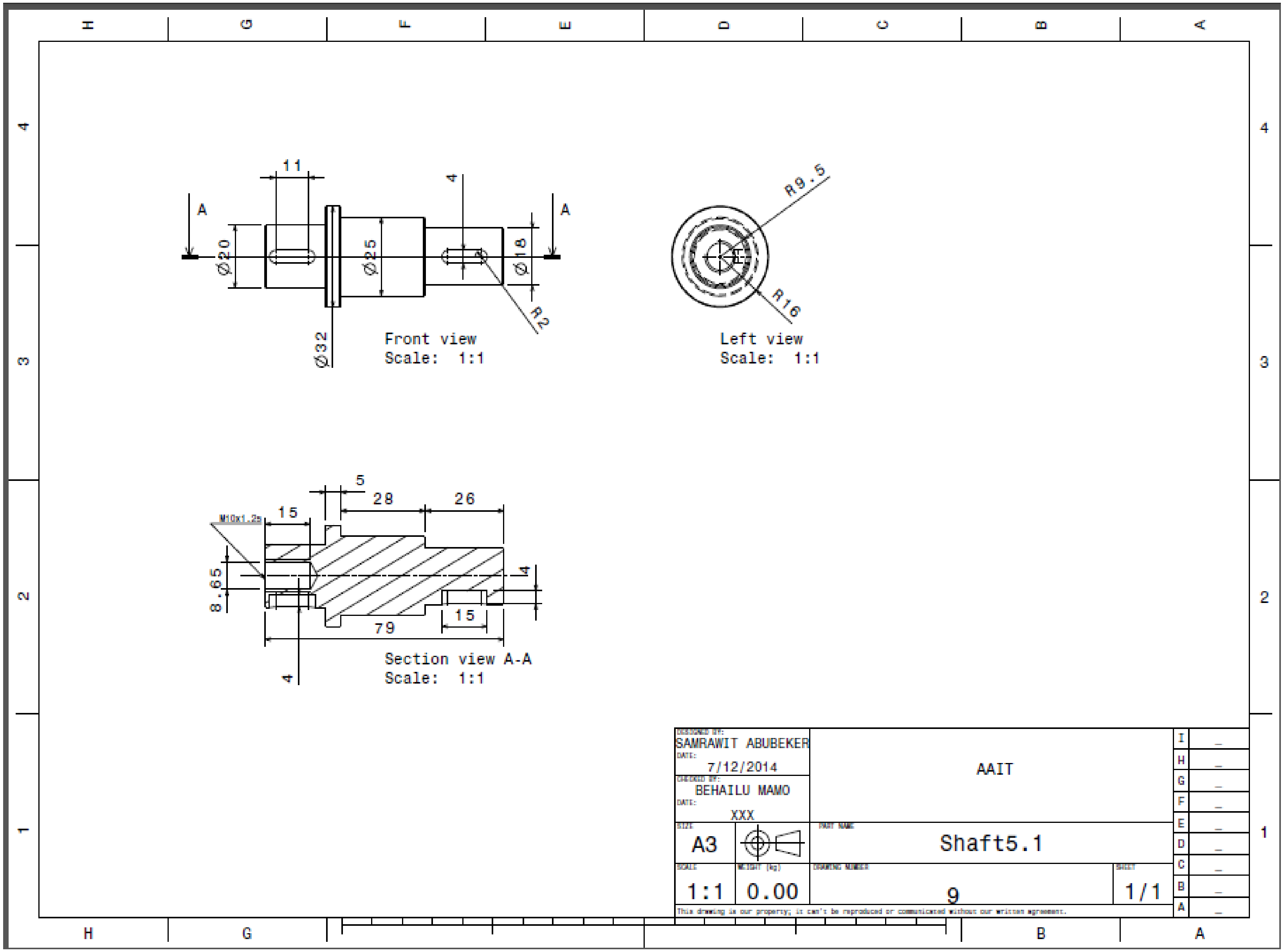
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