

**REDESIGNING THE DONG FANG HONG LOCOMOTIVE SPEEDOMETER
SYSTEM TO SUIT DIESEL ELECTRIC LOCOMOTIVES**

By

Jordan Zimba

**A dissertation submitted to the University of Zambia in partial fulfillment of
the requirements of the degree of Master of Engineering in Production
Engineering and Management**

The University of Zambia

Lusaka

2020

COPYRIGHT DECLARATION

All rights reserved. No part of this dissertation may be reproduced, stored in any retrieval system, or transmitted in any form or by any means, electronic, mechanical, photocopying, recording, scanning or otherwise without the prior written permission of the author or the University of Zambia.

DECLARATION

I Jordan Zimba do hereby make a declaration that I personally wrote this dissertation.

Lusaka, ____ / ____ / ____

Jordan Zimba

CERTIFICATE OF APPROVAL

This dissertation of Jordan Zimba is approved as fulfilling the partial requirements for the award of the degree of Master of Engineering in Production Engineering and Management by the University of Zambia.

NAME	SIGNATURE	DATE
_____	_____	_____
Supervisor & Internal Examiner		
_____	_____	_____
Internal Examiner 1		
_____	_____	_____
Internal Examiner 2		
_____	_____	_____
Internal Examiner 3		
_____	_____	_____
Board of Examiners Chairperson		

ABSTRACT

Thirty four out of forty (85%) TAZARA Diesel Electric (DE) locomotives were operating with either defective or no speedometer system at all. This compromised the safety of locomotives and peoples' lives. As a result of financial challenges, TAZARA was unable buy new DE speedometer system costing over USD\$3,800. Due to estimated travel speeds, it has been extremely difficult to adhere to scheduled train departure and arrival times resulting in the loss of customers and business at large.

The aim of the research is to redesign the abundant DFH₂ speedometer system components and apply them on DE locomotives. Failure to undertake a study would imply rendering all DFH₂ system components in stock obsolete. Concepts and principles relating to the relationship between wheel diameter and worm gear teeth number, assembly requirements for the 1R (C) 2R (P) tachogenerator drive shaft and wheel axle to achieve reliability in the transmission axis were employed to redesign the DFH₂ speedometer system to suit DE locomotives. Two designs involving use of circular and triangular plates to hold the transducer drive shaft were derived and gradually refined to achieve the desired goals.

In both designs the fork assembly was removed, circular and triangular plates were introduced to hold the DFH₂ drive shaft. The worm gear in the DFH₂ mileage counter (odometer) with 34 teeth was replaced by another with 36 teeth to correspond to the DE wheel diameter of 900 mm. One transducer was used for two speedometer gauges on both locomotive ends as opposed to the original DE and DFH₂ locomotive speedometer system installation designs.

In the circular plate design, the plate thickness was increased from 3 mm to 7 mm until an optimum thickness of 6 mm was attained. However, deformations were observed on the peripherals of the plate. In the triangular plate design, no deformations observed and was adopted. The DE standard relationship of locomotive speed and DE locomotive sentry panel voltage (v_{sp}) was used to verify the accuracy of the new system. The results conformed to the DE standards.

In order to verify the performance of the mileage counter (odometer), predetermined distances between particular stations were compared with mileage counter distances. After replacement of worm gear and conducting line tests, the mileage counter readings corresponded to the actual predetermined distances between stations.

In conclusion, therefore, regardless of the type of speedometer system available, it will work accurately on other automobile models if the above concepts and principles are applied accordingly.

Keywords: *Speedometer gauge, Mileage Counter, Transducer, Worm gear teeth number, drive shaft, plate.*

ACKNOWLEDGEMENTS

I would like to thank my supervisors, Professor S.B. Kanyanga and Dr. C.G. Chizyuka from the Department of Mechanical Engineering at the University of Zambia and Mr. F. Banda from the Copperbelt University for the incessant advice and support rendered to me during this research.

This research would not have succeeded without the support of Tanzania Zambia Railways Authority (TAZARA) Mbeya locomotive repair and maintenance workshop staff, Mr. C. Chileshe, Mr. G. Sambala, Mr. O. Mumelo, just to mention a few.

I am grateful for the invaluable support and friendship of my classmate in the 2013 MEng program at the University of Zambia, School of Engineering particularly Mr. Conix Sunday Kalupa.

Many thanks also go to all friends I have met at the University of Zambia for facilitating my stay. I would particularly like to thank my close friends for their support and entertainment. Finally, I would like to recognize and thank my beloved family for their endurance and continuing support.

TABLE OF CONTENTS

Declaration	ii
Notice of Copyright	iii
Certificate of Approval	iv
Abstract	v
Acknowledgements	vi
Contents	vii
List of Figures	xi
List of Tables	xiii
List of Symbols	xiv
Chapter 1	
Introduction	
1.1 Introduction	1
1.2 Problem Statement	5
1.3 Research Objectives	5
1.4 Study Rationale	6
1.5 Methodology	6
1.6 Scope of Study	7
1.7 Layout of the Dissertation	7
Chapter 2	
Literature Review	
2.1 Introduction	9
2.2 Analysis of Modern Trends in Speedometer System Development	10
2.2.1 Current Situation in Southern African Railways	11
2.2.2 Justification for Study	11
2.3 Basic Concepts in Speedometer Redesigning	13
2.3.1 Operational Principle of Mechanical Speedometers	13

2.3.2	Electronic Speedometers Working Principle	15
2.3.3	Transducers	15
2.5	Tachogenerators	17
2.5.1	Tachogenerator Type 1R (C) 2RC (P)	17
2.5.2	Tachogenerator Type TCW	18
2.5.3	Alignment 1R / 2RC (P)	18
2.5.4	Tachogenerator 1R (C) / 2RC (P)	18
2.5.5	Tachogenerator TCW	19
2.6.0	Overview of the DFH ₂ Speedometer	20
2.6.1	Functions of Speedometer System Components	24
2.7	Additional Concepts for Consideration during Redesigning	25
2.7.1	Mounting of Meter and Transducer	25
2.7.2	Cleaning of Mileage Counter	26
2.7.3	Error and Sources of Error	26
2.7.4	Stability In the Meter Indicating Pointer	27
2.7.5	Number of Worm Gear Teeth	27
2.7.6	Wheel Diameter And Travel Speed	28
2.7.7	Connection of Transducer With Wheel Axle	28
2.7.8	Low or No Speed Indication Of Speedometer	28
2.8	General Instrument Calibration	29
2.8.1	Zero and Span Adjustment (Analog Instruments)	30
2.8.2	Speedometer Accuracy and Calibration	32
2.9	DE Locomotive Rail Line Test Standards	34
2.10	Analysis of the DFH ₂ and DE Speedometer Systems	35
2.10.1	Analysis of the Energy Conversion Process	35
2.10.2	DE and DFH ₂ Speedometer System Outputs	35

Chapter 3

Materials and Methodology

3.1	Introduction	37
3.2	Alternative Speedometer System	38
3.3	Variations between the Speedometer Systems (DFH ₂ and DE Systems)	38
3.3.1	Interaction of Parts in Speedometer Systems	38
3.3.1.1	DFH ₂ System	39
3.3.1.2	DE System	41
3.4	Measurements	44
3.4.1	Dismantling system Components	44
3.4.2	Cleaning of Components	44
3.4.2	Surface Plate	44
3.5	Comparison of Speedometer system components	45
3.6	Determination of Component Parts to Redesign	46
3.7	Pictorial and Final Engineering Drawings	50
3.8	Calibration	57
3.9	Rail-Line Tests	57
3.10	System Refinement and Documentation	59

Chapter 4

	Redesign and Manufacture of the System	61
4.1	Introduction	61
4.2	Redesigning System Components	61
4.2.1	Redesigned System Components and Specifications	61
4.3	Redesign or Buy Decision Options	65

Chapter 5	
Line Tests Results and Discussion	
5.1	Introduction 67
5.2	Calibration and Adjustment Test Results 67
5.3	Line Test Results 72
Chapter 6	
Conclusions and Recommendations	
6.1	Introduction 79
6.2	Conclusions 79
6.3	Findings and Outcomes 80
6.4	Limitations and Recommendations 80
References	81
Appendix A	
	Table for wheel diameter, axle rotating speed and travel speed 85
Appendix B	
	Exploded Diagram of A Typical Speedometer 86
Appendix C	
	Motion Sensors/ Transducers 87
Appendix D	
	Odometer 88
Appendix E	
	Calibration 94
Appendix F	
	Calculation of tire turns per mile 95
Appendix G	
	Cross Sectional Drawings Position Of Components – 1R (C) 96
Appendix H	
	Planned maintenance 99
Appendix I	
	Troubleshooting 102

LIST OF FIGURES

Figure 1.1:	DE locomotive (TAZARA Website, 2015)	1
Figure 1.2:	DFH ₂ locomotive (TAZARA Website, 2015)	2
Figure 1.3:	Unshielded Transducer	3
Figure 2.1:	Mechanical Speedometer	14
Figure 2.2:	Cross-section of a Mechanical Speedometer (Rhodes, 2000)	14
Figure 2.3:	Energy Transformation in a Transducer	15
Figure 2.4:	Transducer (Norton, 2015)	16
Figure 2.5:	Sensors and Actuators	16
Figure 2.6:	General view of a transducer	17
Figure 2.7:	Flexible Coupling (Source, ibid)	19
Figure 2.8:	Coupling Arrangement (Source, ibid)	19
Figure 2.9:	TCW tachogenerator Coupling Arrangement (Source, ibid)	20
Figure 2.10:	Transducer (Dong F.H., 1974)	21
Figure 2.11:	DFH ₂ Speedometer (Dong F.H., 1974)	21
Figure 2.12:	A Directional Figure (Dong F.H., 1974)	22
Figure 2.13:	DFH ₂ Mechanical Driving and Electrical Operating Principle	26
Figure 2.14:	Relative Position of Pushrod and Ratchet Wheel	26
Figure 2.15:	Worm Gear	28
Figure 2.16:	How input and out of an instrument should relate	30
Figure 2.17:	Graph Indicating Input and Output of a Pressure Transmitter	31
Figure 2.18:	DFH ₂ Speedometer	33
Figure 2.19:	DFH ₂ Speedometer Test Stand	34
Figure 3.3:	Connection of DFH ₂ Transducer to Wheel Axle	40
Figure 3.4:	Front View of DFH ₂ Circular Plate	40
Figure 3.5:	Side and Front View of DFH ₂ Fork Assembly	41
Figure 3.6:	DE locomotive suspended on lifting jacks	42
Figure 3.7:	DE wheel set	42
Figure 3.8:	Connection of DE Transducer to Wheel Axle	43

Figure 3.9:	Front and Side View of DE Circular Plate	43
Figure 3.10:	Front view of triangular plate connected to DE wheel axle	49
Figure 3.11:	Final DFH ₂ based Speedometer System installed on DE 1027	50
Figure 3.12:	Interaction of parts – initial DFH ₂ system (front view)	51
Figure 3.13:	Interaction of parts – initial DFH ₂ system (side view)	51
Figure 3.14:	Engineering Drawings for the initial DFH ₂ system	51
Figure 3.15:	Pictorial Drawings for the initial DFH ₂ system (Front view)	52
Figure 3.16:	Pictorial Drawings for the initial DFH ₂ system (Side view)	53
Figure 3.17:	Engineering Drawings for the final DFH ₂ system	54
Figure 3.18	DE journal box cover	55
Figure 3.19	U-Shaped bracket for Shielding Transducer	56
Figure 3.20	Circular and Triangular Plates	59
Figure 5.1	Trends in Calibration results	68
Figure 5.2	Actual Distance Vs Mileage Counter Readings	72
Figure 5.3	Relationship between Speed and V_{sp}	75

;

LIST OF TABLES

Table 2.1:	DE locomotive Standard Relationship between sentry panel voltage and speed	35
Table 3.1	DE and DFH ₂ System Components & their Dimensions	46
Table 3.2:	Record Sheet – Voltage and locomotive speed	57
Table 3.3:	Record Sheet of Actual Distance and Mileage Counter Readings	58
Table 3.4	DE Speedometer System Components & their Dimensions	64
Table 3.5	Redesign or Buy Decision Options	65
Table 5.1:	Calibration Results	68
Table 5.2:	Calibration Results after replacement of Spiral Spring	70
Table 5.3:	Speed Comparisons after pointer adjustments	71
Table 5.4:	Calibration Results at wheel diameter of 900mm	72
Table 5.5:	Line Test Results of DFH ₂ Speedometer System at wheel diameter 900mm	73
Table 5.6:	Line Test Results at Circular Plate thickness of 6mm	75
Table 5.7:	Line Test Results using a triangular plate of 6mm thickness	76
Table 5.8:	Line Test Results of Actual Distance and Mileage Counter Readings	78

LIST OF SYMBOLS

F	[n, newton]	Force
I_1	[A, Amps]	DFH ₂ input current
I_2	[A, Amps]	DFH ₂ tachogenerator output current
P_1	[w, watts]	Input power to DFH ₂ transducer
P_2	[w, watts]	Output power from DFH ₂ transducer
P_{in}	[w, watts]	Input power
P_{out}	[w, watts]	Output power
V	[v, volts]	Voltage
V_1	[v, volts]	DFH ₂ output voltage
V_2	[v, volts]	DFH ₂ tachogenerator output voltage
V_3	[v, volts]	DE tachogenerator output voltage
V_{sp}	[v]	Sentry panel volatge
V_{de}	[Km/h]	DFH ₂ speedometer gauge reading
V_{dfn}	[Km/h]	DE locomotive standard speedometer reading
\emptyset	[mm]	Wheel diameter

LIST OF ABBREVIATIONS

CBU	Copperbelt University
DE	Diesel Electric Locomotive
DFH	Dong Fang Hong Locomotive
GRZ	Government of the Republic of Zambia
LRV	Lower Range Value
MP	Motive Power
MTU	Motor (Engine) and Turbine Union
PBT	Polybutylene
PW	Permanent Way
RC	Rectifier Circuit
TAZARA	Tanzania Zambia Railway Authority
UNZA	University of Zambia
URT	United Republic of Tanzania
ZRL	Zambia Railways Limited

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Tanzania Zambia Railway Authority (TAZARA) is owned by two shareholding Governments of the United Republic of Tanzania (URT) and the Government of the Republic of Zambia (GRZ). From inception to date, TAZARA has used four types of main line locomotives: Dong Fang Hong (DFH₂), Repowered MTU, Diesel Electric (DE) and the Dalian. Before handover in 1975, the Government of the People's Republic of China brought a lot of backup spares for the DFH₂ locomotives. To date, most of DFH₂ spares, including the speedometer system parts were still in stock in the locomotive spares stores because only one DFH₂ locomotive was available in Tanzania for shuttle train operations and shunting purposes. The other fleet of DFH₂ locomotives was defective and not utilised for main line operations. Figures 1.1 and 1.2 show the DE, and DFH₂ locomotives.



Locomotive Bumper

Figure 1.1: DE locomotive hauling a passenger train

(Source: TAZARA, 2015)



Figure 1.2: DFH₂ locomotive hauling a passenger train

(Source: TAZARA, 2015)

TAZARA is currently using DE locomotives for main line operations. The Authority has a total fleet of forty (40) DE locomotives. About 34 (85%) of the DE locomotives were operating with either defective or no speedometer system at all. Many of the DE locomotives and peoples' lives have been lost through accidents attributed to over speeding on the part of locomotive drivers. During the accident analysis meetings held in 2014 it was reported that approximately three (3) accidents annually were attributed to over speeding. About 85% of the DE tachogenerators were lost along the railway whenever they hit foreign obstacles on the rail line making the option of repairing them impossible. The speedometer system for one DE locomotive end costs over USD\$3,800. TAZARA has been undergoing serious financial hardships to the extent of failing to pay salaries and benefits for its workers and retirees. As a result of using locomotives without speedometer system, it has been extremely difficult to adhere to scheduled times culminating in the loss of customers and business. Figure 1.3 shows how tachogenerators are connected to DE and DFH₂ wheel axles.



Figure 1.3: Unshielded DFH₂ transducer connected to the wheel axle.

Most of the locomotives in third world countries like Zambia are imported from developed countries where track maintenance is done according to planned schedules and stipulated standards. By doing so, tracks are obstacle-free making it unnecessary to shield the tachogenerators during manufacture. Most speedometer systems were designed for particular locomotive models with the same axle size, journal box cover arrangement and wheel diameter among other things. Such speedometer systems (e.g. very old models like the DFH₂) were not designed and made to be fitted on other locomotives especially the much newer models like the DE locomotives for TAZARA. The effect of changing the size, geometry and introducing other suitable parts on a particular system to facilitate compatibility has not been explored. This research looked at redesigning some DFH₂ speedometer system parts to suit DE locomotives. The research on speedometer accuracy (Hansard, 2001) and Dong F. H. (1974) recognised and stipulated the importance of having and mounting the tachogenerator with the wheel axle linearly and reliably. The research did not take into account the possibility of various obstacles finding their way onto track and causing damage and possibly detaching the

unshielded tachogenerator as the locomotive moved. The possibility of introducing a bracket to protect the tachogenerator needed to be investigated in addition to ensuring that the bracket should facilitate repair and service of the tachogenerator. The research on the relationship between sentry panel voltage and travel speed (Krupp, 1980) looked at ascertaining the accuracy of a DE speedometer system whilst the locomotive was in transit. The relationship between other speedometer systems (DFH₂ system) and DE sentry panel voltage needed to be investigated to determine their compatibility.

The technical staff from particular TAZARA workshops attempted to address the problem of speedometer system through repair of defective DE systems and procurement of new DE speedometer system. Both attempts did not succeed as there were no DE speedometer system backup spares in stores and the Authority did not have the financial capacity to buy new DE systems. It was therefore, imperative to seek cheaper avenues of providing speedometer systems on the DE locomotives. This research looked at redesigning some DFH₂ speedometer system parts to suit DE locomotives while maintaining the original DFH₂ 3 – phase wiring system.

Type DJS-II Locomotive Speedometer system is adopted on the DFH₂ Locomotive to indicate the travel speed and total mileage travelled. It is vital for locomotive driver to keep the train travelling safe and punctual. This speedometer system includes an electric meter for non-electric measurement that makes use of a tachogenerator in connection with a magnetic type electric meter. This system consists of three parts namely: indicating meter (abbreviated as meter); transducer and connecting cord. This meter was designed for mounting on driver's desk and transducer on the bogie axle box cover. The driving shaft of transducer is coupled flexibly with locomotive wheel axle. This indicating meter is coupled to transducer through a specially designed plug-in type connecting cord. This meter features with its simple construction, adjustable indicating speed and requires little maintenance, (Dong F. H. 1974).

1.2 PROBLEM STATEMENT

About 34 out of 40 (85%) DE locomotives were operating with either defective or no speedometer system at all. This has been prompting drivers to estimate travel speed and as such, many locomotives and peoples' lives have been lost through accidents attributed to over speeding. Most of the DE tachogenerators were damaged or lost whenever they hit various obstacles on the railway. The speedometer system for one locomotive end costs over USD\$3,800. TAZARA has been undergoing enormous liquidity problems making it impossible to procure a new DE speedometer system. Due to estimated travel speeds, it has been extremely difficult to adhere to scheduled departure and arrival times resulting in the loss of customers and business at large.

1.3 RESEARCH OBJECTIVES

The main objective of this research was to make the DFH₂ speedometer system compatible with the DE system. To achieve this, the following were identified as specific objectives:

- i. To redesign and adjust the DFH₂ speedometer system component(s) or part(s) to ensure that they were installed and operated successfully on DE locomotive;
- ii. To configure/match the adjusted DFH₂ based speedometer with transducer through laboratory calibration and adjustment;
- iii. To establish the best way of protecting the transducer while taking into account the need for it to be serviced or repaired;
- iv. To develop table(s) of system parameters test results obtained by subjecting the locomotive unit to rail line tests and
- v. To determine the accuracy of the new DFH₂ based speedometer system by comparing test results in (IV) to DE standard test tables.

1.4 STUDY RATIONALE

The justification for this research can be drawn from the fact that TAZARA has capacity in terms of design and manufacturing. The Authority has three large workshops that are handsomely equipped with various equipment/shops – forge and foundry, pattern making, carpentry, machining, and metal fabrication shops. TAZARA also has two Central Laboratories that are equipped with various Testing Stands such as the Speedometer Testing Stand. In railway transport business, the possibility of accidents cannot be over emphasised. As a result of such calamities and other activities, there is enough scrap available to facilitate making of parts that could be deemed necessary for speedometer system.

TAZARA is undergoing financial difficulties and therefore, is not in a position to buy new speedometer systems for the affected locomotives. Furthermore, many locomotives are being lost in accidents that are attributed to over speeding. Drivers just use acquired experience to estimate the travel speed and the trend cannot be allowed to continue as more locomotives would be lost in accidents.

Before handover of TAZARA in 1975, the Government of the People's Republic of China left large stocks of DFH₂ speedometer system components that were still in the locomotive spares stores. These were enough to cater for all the DE locomotives in operations.

1.5 METHODOLOGY

In order to achieve the set goals the following methodology was adopted:

- I. Component parts investigation through interaction of parts and measurements;
- II. Determination of variations between DE and DFH₂ systems part(s) or component(s) arising from parts investigations;

- III. Redesigning and machining/fabrication or stores requisitions;
- IV. Assembly and configuration of redesigned parts and laboratory calibration;
- V. Installation on locomotive, rail line tests, monitoring and recording of performance and new system adjustment/refinement;
- VI. Comparison of new system performance to DE set performance standards and;
- VII. Conclusions and Recommendations.

1.6 SCOPE OF STUDY

The work was carried out at Mbeya (Tanzania) DE Locomotive Repair and Maintenance Workshop. The study was undertaken on locomotive number DE1027. Machining and Fabrication methods available in Mbeya workshops and DFH₂ Speedometer Test Stand in Dar-es-Salaam workshop were employed to accomplish the study. The study did not include the development of optimization algorithms but focused on available DE and DFH₂ set standards for analysis of new system performance.

1.7 LAYOUT OF THE DISSERTATION

The general focus of this study was to redesign the DFH₂ system to suit DE locomotives.

Chapter one explains the background on locomotive speedometer system in TAZARA, cause of loss of the DE speedometer system, challenges encountered as a result of using locomotives without speedometer system and gaps in the field of speedometer system (Control system).

The chapter briefly introduces the DFH₂ locomotive speedometer system, and justifications for the study have been adequately covered.

The remainder of the dissertation has been arranged as follows:

Chapter two presents trends in the development of speedometer system. It goes further to identify the gaps by analyzing and comparing the developments with what is actually obtaining in the industry thereby providing a justification for the study.

Chapter three presents the types of speedometer systems, their operational principles and some basic concepts related to some important components (transducers) of a speedometer system. An overview of the DFH₂ speedometer system is also given.

Drawing from the concepts of chapter three, chapter four presents an analysis of the energy conversion process that would bring out compatibility between the outputs of the DE and DFH₂ systems. It goes further to provide the process used in the determination of parts for redesigning or adjusting.

Chapter five presents steps undertaken in the speedometer development process and justifications for adopting certain decisions and methods of manufacturing or adjustment of particular parts.

Chapter six presents what constituted redesigning and manufacture of the DFH₂ based speedometer system components. This chapter, further highlights and stipulates the final adopted system components and their respective specifications.

Chapter seven presents results obtained during calibration, adjustment of the system components, rail line tests and discussions thereof to ascertain the performance and conformance of the redesigned DFH₂ speedometer system to DE locomotive standards. Chapter eight summarises the conclusions and recommendations for implementation by Tanzania Zambia Railway Authority (TAZARA).

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter presents trends in the development of a speedometer systems. This chapter further presents the basic concepts in speedometer system, overview of the DE and DFH₂ speedometer systems and their analysis to aid determination of compatibility between two systems. It goes further to identify the gaps by analyzing and comparing the developments with what is actually obtaining in the industry thereby providing a justification for the study.

The concept of recording travel data is almost as old as the concept of vehicles. Early Romans marked the wheels of their chariots and counted the revolutions; estimating distance traveled and average daily speed. In the eleventh century, Chinese inventors came up with a mechanism involving a gear train and a moving arm that would strike a drum after a certain distance. Nautical speed data was recorded in the 1500s by an invention called the chip log, a line knotted at regular intervals and weighted to drag in the water. The number of knots let out in a set amount of time would determine the speed of the craft, hence the nautical term “knots” still applied today (William E., 1973)

The first patent for a rotating-shaft speed indicator was issued in 1916 to inventor Nikola Tesla. At that time, however, speedometers had already been in production for several years. The development of the first speedometer for the cars is often credited to A. P. Warner, founder of the Warner Electric Company. At the turn of the century, he invented a mechanism called a cut-meter, used to measure the speed of industrial cutting tools. Realising that the cut-meter could be adapted to the automobile, he modified the device and set about on a large promotional campaign to bring his speedometer to the general public. Several speed indicator concepts were introduced by competing sources at the time, but Warner’s design enjoyed considerable success.

By the end of World War I, the Warner Instrument Company manufactured nine out of every ten speedometers used in automobiles (Nikola T. 1916)

The Oldsmobile Curved Dash Runabout, released in 1901, was the first automobile line equipped with a mechanical speedometer. Cadillac and Overland soon followed, and speedometers began to regularly appear as a factory-installed option in new automobiles. Speedometers in this era were difficult to read in daylight and, with no lamp in the housing, virtually illegible at night. The drive cable in early models was attached to either the front wheels or the back of the transmission, but the integration of the drive cable into the transmission housing would not happen for another twenty years. After that improvement was made, the basic technical design of a speedometer would remain untouched until the advent of the electronic speedometer in the early 1980s.

The early speedometer systems were designed only to indicate travel speed until in the later years when the odometers began to be incorporated in the speedometer housing as a single unit for the purpose of indicating both travel speed and distance traveled.

Materials used in the production of speedometers vary with the type of gauge and intended application. Older mechanical models were entirely comprised of steel and other metal alloys, but in later years about 40% of the parts for a mechanical speedometer were molded from various plastic polymers. Newer electronic models are almost entirely made of plastics and design engineers continually upgrade the polymers used. For example, the case of a speedometer's main assembly is usually made of nylon, but some manufacturer's now employ the more-water resistant polybutylene (PBT) polyester. The worm drive and magnet shaft are also nylon, as is the speedometer's gear train and spindles. The glass display lens of the recent past is now made of transparent polycarbonate, a strong, flexible plastic that is resistant to heat, moisture and impact.

2.2 ANALYSIS OF MODERN TRENDS IN SPEEDOMETER SYSTEM DEVELOPMENT AND

JUSTIFICATION FOR STUDY.

Most speedometer systems are being made for particular models of vehicles and usually not interchangeable between different models from various manufacturers. This position generally applies to both locomotives and motor vehicles. The old vehicles and speedometers were mainly designed with low speeds of up to around a maximum of 100 km/h while the modern practice has been advocating for the manufacture of high speed vehicles and speedometers incorporating other facilities such as the provision of alarms, lamps, thermometers to mention but a few. In the newer models continuous efforts have been made to change and improve on the materials used.

The current repair and maintenance system of modern speedometers involves servicing components of a particular speedometer model, replacing defective components or entire speedometer system with a similar one.

2.2.1 CURRENT SITUATION IN SOUTHERN AFRICAN RAILWAYS

Most of the railways in the Southern Africa countries were constructed after 1900 and most of them have not undergone some tangible rehabilitation and upgrade. In Zambia this situation applies to both Zambia Railways Limited (ZRL) and the Tanzania Zambia Railway Authority (TAZARA). This lack of rehabilitation led to the dilapidation of the permanent way (PW) over time and a significant reduction in travel speeds in some railway sections.

For TAZARA the first fleet including most of the existing rolling stock was supplied by the Government of the People's Republic of China. Different Motive power (MP) with different speedometer system technologies has been supplied to TAZARA over time.

The most part of the TAZARA permanent way passes through thick forests and steep gradients especially on the Tanzanian side.

2.2.2 JUSTIFICATION FOR STUDY

Most of the TAZARA locomotives were running with either defective or no speedometer system due to lack of capacity to buy new ones and design deficiencies. A huge number of locomotives were since inception lost through accidents mainly attributed to over speeding. The speedometer system on current fleet of DE locomotives is costing over USD\$3,800.

Most of the studies on speedometer system have been centered on developing an absolutely new speedometer system for new and particular vehicle models. No or little effort has been made to develop speedometer systems that would be universally used on both old locomotives such as the DFH₂ locomotives and much new models such as the DE locomotives.

Despite that the DE locomotives are much newer and have the capacity to run faster, the current speeds for both freight and passenger trains in TAZARA and ZRL averages 50km/h and 20km/h respectively due to the dilapidated state of the permanent way. The DFH₂ speedometer gauge has a maximum speed of 120km/h which is way beyond the average speed.

TAZARA has large stocks of DFH₂ based speedometer system components which if redesigned and applied successfully on the DE locomotive would really be an enormous cost saving option. On the other hand, failure to undertake a study would imply rendering all the DFH₂ speedometer system in stock obsolete.

The locomotive drivers just estimate the travel speed basing on experience but, nevertheless, most of the experienced drivers had retired leaving more of the newly employed ones. This state of affairs posed a risk not only to the rolling stock and freight goods but also to the lives of the passengers and train crews as a whole.

Most of the DE locomotives did not have speedometer systems due to lack of transducers that usually got damaged or detached whilst in transit as they hit or came in contact with foreign obstacles on the railway. Therefore, leaving the status quo (not undertaking a study) would imply losing all the unshielded transducers thereby rendering most speedometer systems non-operational.

2.3 BASIC CONCEPTS IN SPEEDOMETER REDESIGNING

Prior to redesigning, it is imperative to appreciate the types of speedometer systems, their operational principles and some basic concepts related to some important components of a speedometer system. An overview of the DFH₂ speedometer system is also given.

There are basically two types of speedometer systems namely: mechanical (eddy-current) invented by Otto Schulze in 1902 and the Electronic speedometers. Figures 3.1 and 3.2 show the basic and cross-section of mechanical speedometer.

2.3.1 OPERATIONAL PRINCIPLE OF MECHANICAL SPEEDOMETERS

- i. When the engine turns on, the driveshaft turns to make the wheels spin round.
- ii. The speedometer cable, powered by the driveshaft, turns as well.
- iii. The cable spins a magnet around at the same speed inside the speed cup. The magnet rotates continually in the same direction (in this case, counter-clockwise).
- iv. The spinning magnet creates eddy currents in the speed cup.
- v. The eddy currents make the speed cup rotate counter-clockwise as well in an attempt to catch up with the magnet. The magnet and the speed cup are not joined together in any way- there is air between them.
- vi. The hair spring tightens, restraining the speed cup so it can turn only a little way.
- vii. As the speed cup turns, it turns the pointer up the dial, indicating the vehicle's speed.

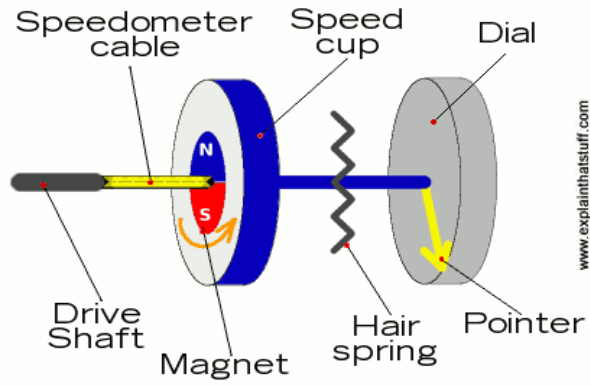


Figure 2.1: Mechanical Speedometer
 (Source: Rhodes, 2000)

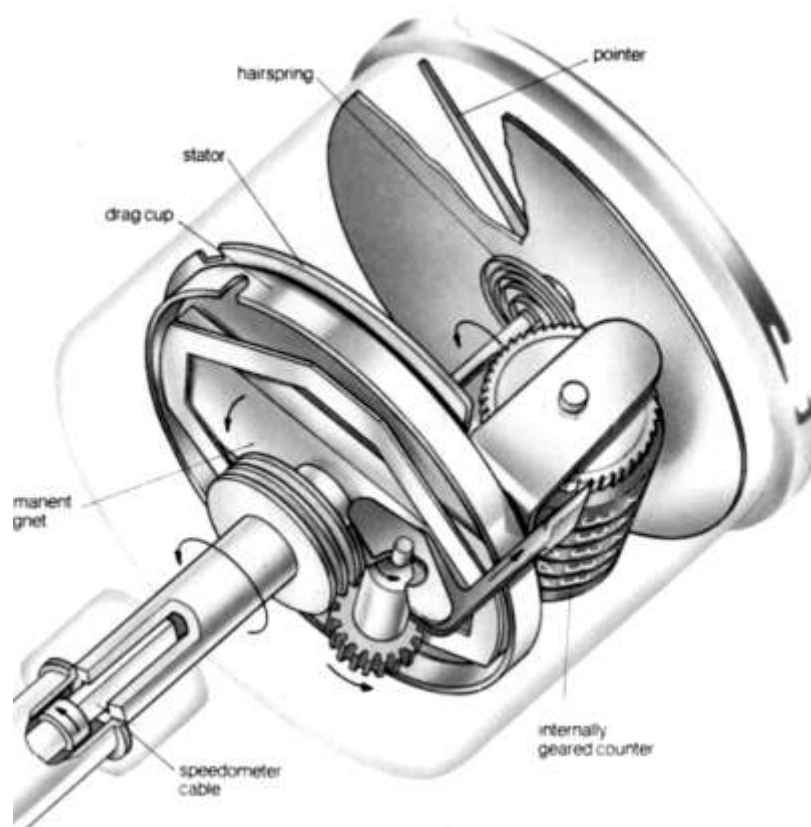


Figure 2.2: Cross-section of a mechanical speedometer
 (Source: Rhodes, 2000)

2.3.2 ELECTRONIC SPEEDOMETERS WORKING PRINCIPLE

Many modern speedometers are electronic. In designs derived from eddy-current models, a rotation sensor transmission delivers a series of electronic pulses whose frequency corresponds to the (average) rotational speed of the drive shaft, and therefore the vehicle's speed, assuming the wheels have full traction. The sensor is typically a set of one or more magnets mounted on the output shaft or (transaxles) differential crown wheel, or a toothed metal disc positioned between a magnet and a magnetic field sensor.

2.4 TRANSDUCERS

There are many definitions of transducers. A transducer is a device which transforms a non-electric energy into electrical energy and vice versa (Qing-Ming W., 2012). Figure 3.3 shows the energy transformation in a transducer

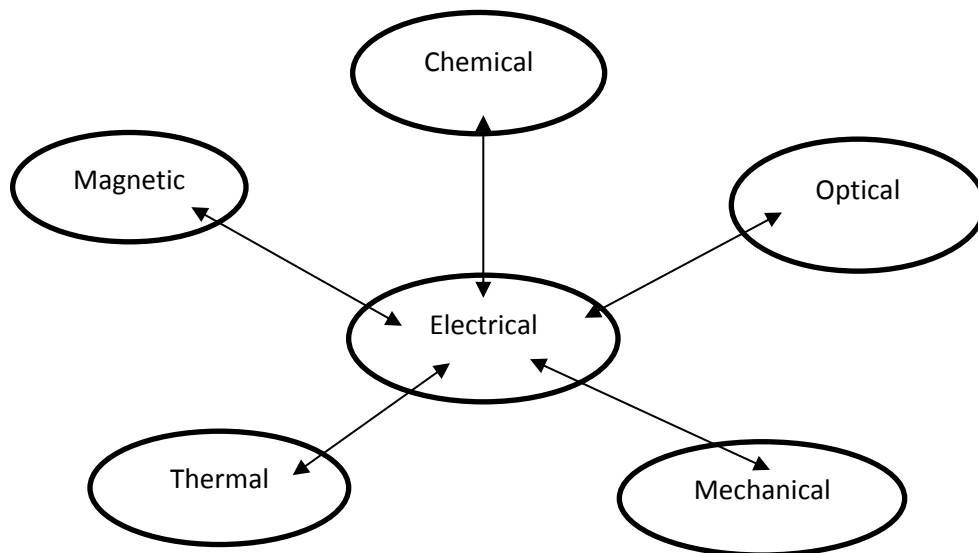


Figure 2.3: Energy transformation in a Transducer
(Source: Lang, 2001)

Transducers may generally be divided into two classes:

- Sensors, which monitor the system; and
- Actuators, which impose a condition on a system.

Sensors and actuators are comprehensive classes of transducers. Some transducers can operate as sensor or as actuators, but not as both simultaneously. Figures 3.4, 3.5 and 3.6 show the basic transducer, Sensors and Actuators and the general view of a transducer – a two (2) Port device. Appendix C further provides examples of motion sensors/transducers.

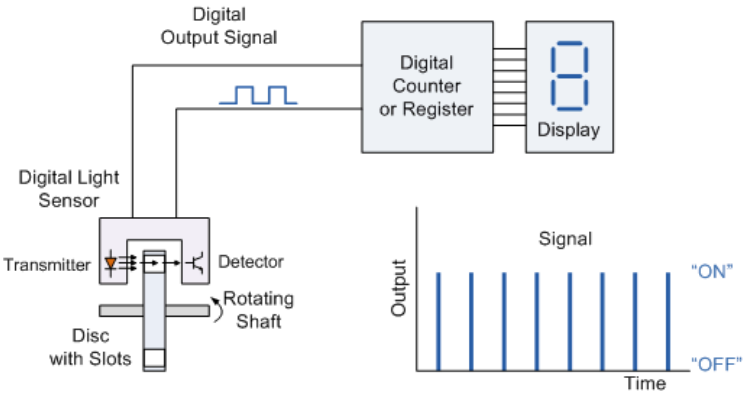


Figure: 2.4: Transducer (Source: Norton, 2015)

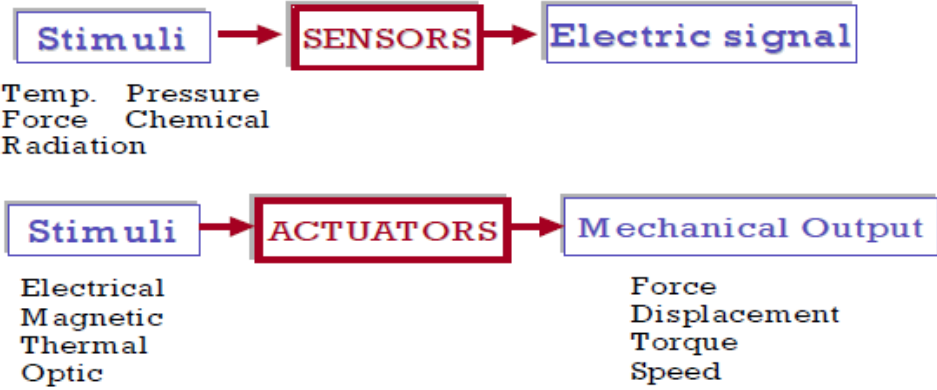


Figure 2.5: Sensors and Actuators
(Source: Mir-Nasiri, 2015)

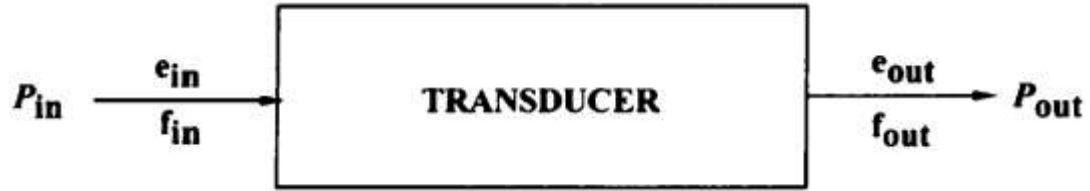


Figure 2.6: The General View of a Transducer: A two (2) Port device
(Source: Norton, 2015)

The P_{in} is the input power (P). The f and e are two power conjugate variables which when multiplied yield the power in a given energy domain, such as voltage (V) and current (I) for an electrical port, or a force (F) and a velocity (v) for a mechanical port. P_{out} is the output power. The ratio analogous to the electrical impedance (voltage/current) is defined as the impedance (Norton, 2015). Examples:

$$P = V \times I = \text{Voltage} \times \text{Current} \quad (2.1)$$

$$P = F \times v = \text{Force} \times \text{velocity} \quad (2.2)$$

2.5 TACHOGENERATORS

The tachogenerators are designed to provide a continuous voltage sign corresponding to the speed actual value of the unit to which it is connected. The tachogenerator is fitted with permanent magnets in a stator with the function of creating a magnetic field. An amplitude continuous voltage proportional to the speed which depends on the rotation direction is generated in the wound rotor.

2.5.1 TACHOGENERATOR TYPE 1R (C) 2RC (P)

The type 1R (C) 2RC (P) tachogenerator is fitted with a flange and its drive shaft with key. With these features coupling arrangement is achieved through flexible coupling. This type of

tachogenerators are built with a terminal box for connection to an output device such as a speedometer. The “C” and “P” indicate that the tachogenerators are built with feet or T-box.

It is recommended that type 1R (C) 2RC (P) tachogenerators should not be disassembled because of the characteristics of the permanent magnets used. This is because when the rotor is dismounted from the stator, magnets become partially demagnetized and then the tachogenerator will not supply the voltage rated value.

2.5.2 TACHOGENERATOR TYPE TCW

The type TCW tachogenerator is built with hollow drive shafts where the rotor is installed over a conic extension of the machine shaft to which it is coupled. The magnetic material of the magnets is a stabilized AlNiCo, which does not become demagnetized when the tachogenerator is dismounted or mounted. Figure 2.9 shows type TCW Tachogenerator coupling system.

2.5.3 ALIGNMENT 1R / 2RC (P)

The alignment of the tachogenerator drive shaft and the unit to which it is connected must create perfect parallelism and concentricity to prevent vibrations.

2.5.4 TACHOGENERATOR 1R (C) / 2RC (P)

This Tachogenerator requires a suitable flexible coupling to compensate vibrations and small mounting inaccuracies (supplied optionally): it is supplied with feet and flange; and a manufacturer can be contacted for belt driving. Figures 2.7 and 2.8 provides the Flexible coupling system and mechanisms.

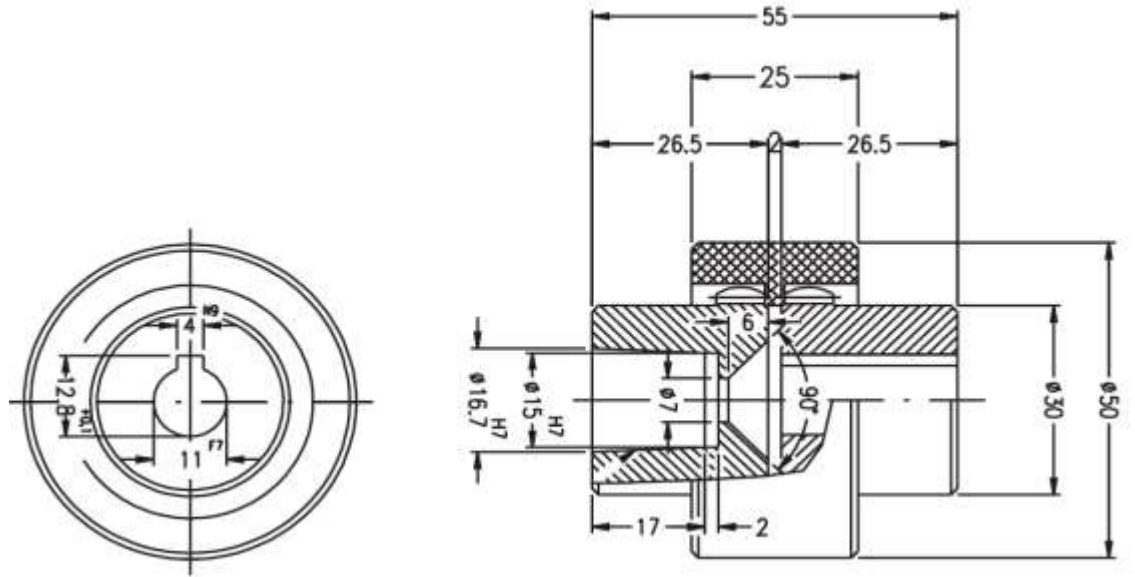


Figure 2.7: Flexible Coupling system (Source: ibid)

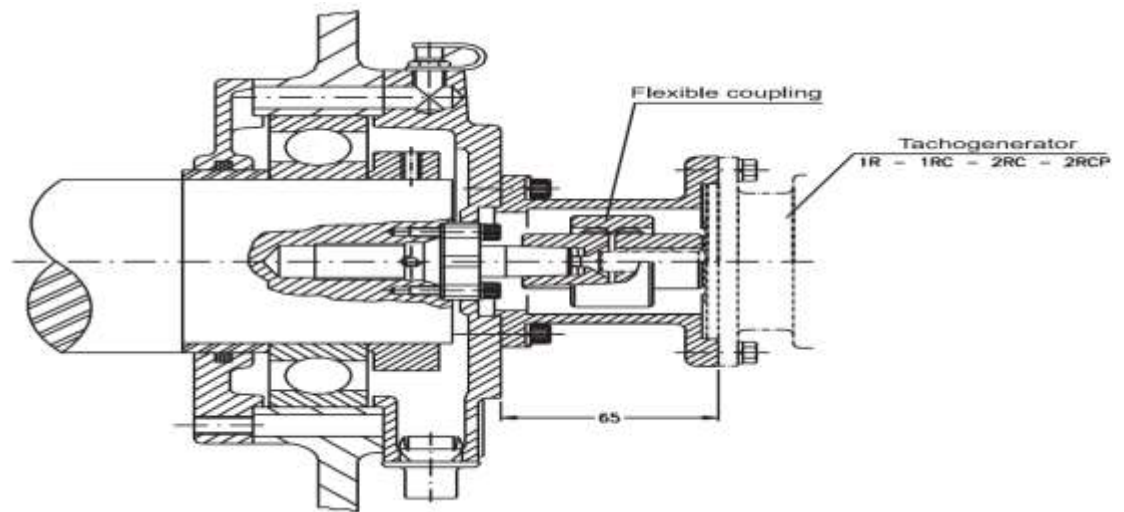


Figure 2.8: Coupling mechanism (Source: ibid)

2.5.5 TACHOGENERATOR TCW

Type TCW tachogenerator is fitted with tempered shaft which must be fixed on the machine shaft extension to which it is connected. The fixation of the motor on the machine shaft is made by using a MC × 20 bolt and a pressure washer. The TCW frame is fixed on the motor end shield.

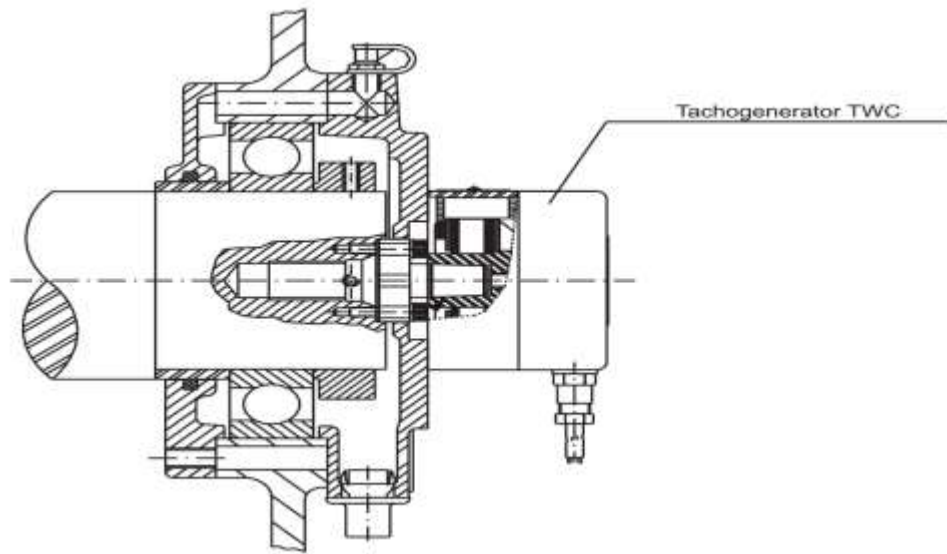


Figure 2.9: TCW Tachogenerator coupling system (Source: ibid)

2.6 OVERVIEW OF THE DFH₂ SPEEDOMETER

The DFH₂ speedometer system consists of three parts, namely indicating meter, transducer and connecting cord. This meter is designed for mounting on driver's desk and transducer on bogie axle box cover. The driving shaft of transducer is coupled flexibly with locomotive axle. This indicating meter is coupled to transducer through a specially designed plug-in type connecting cord.

The DFH₂ speedometer gauge is simple in construction and requires little maintenance and as such is widely used in diesel and electric locomotives as well as other types of rail vehicles (Dong F.H. 1974). Figures 2.10, 2.11 and 2.12 show a DFH₂ transducer, speedometer and a directional figure of the speedometer. Figure 2.13 shows the mechanical and electrical operating principle of the transducer.

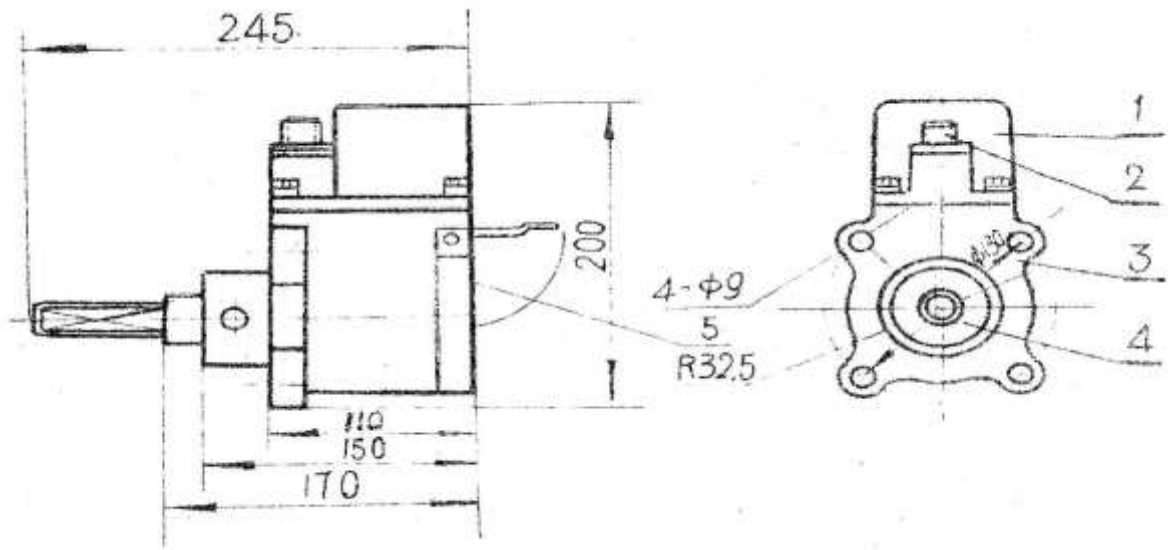


Figure 2.10: Transducer
(Source: Dong F.H., 1974)

1. Tachometer generator
2. Signal output receptacle
3. Shell
4. Driving shaft
5. Mileage Counter

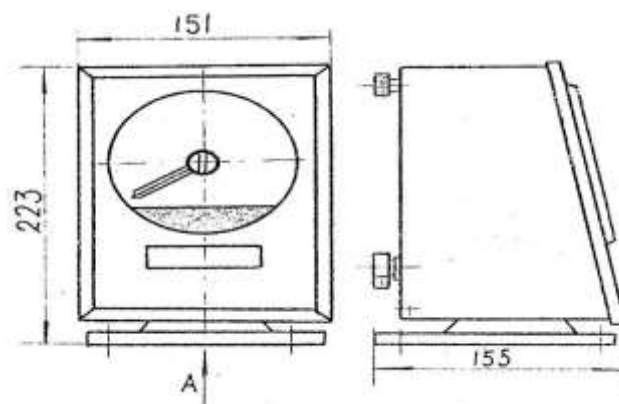


Figure 2.11: Speedometer
(Source: DFH₂ Repair & Maintenance Manual, 1974)

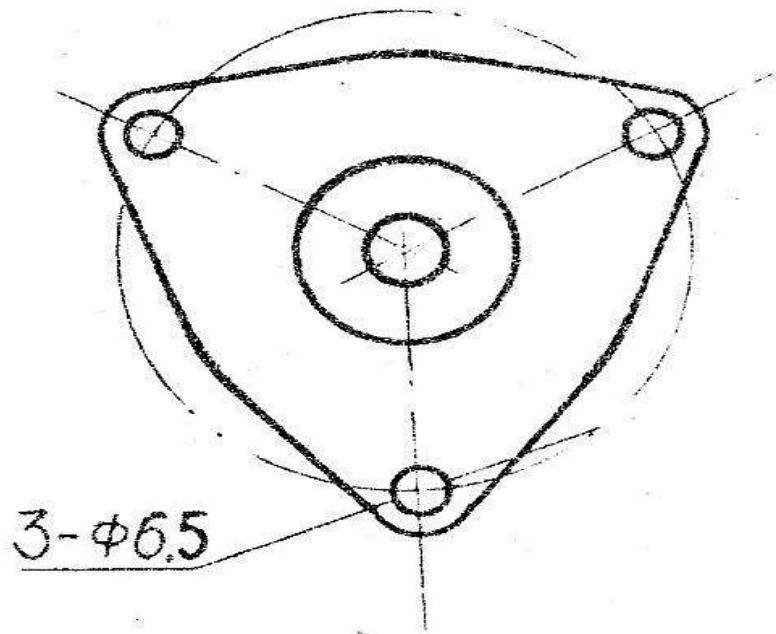


Figure 2.12: "A" Directional figure
(Source: DFH₂ Repair & Maintenance Manual, 1974)

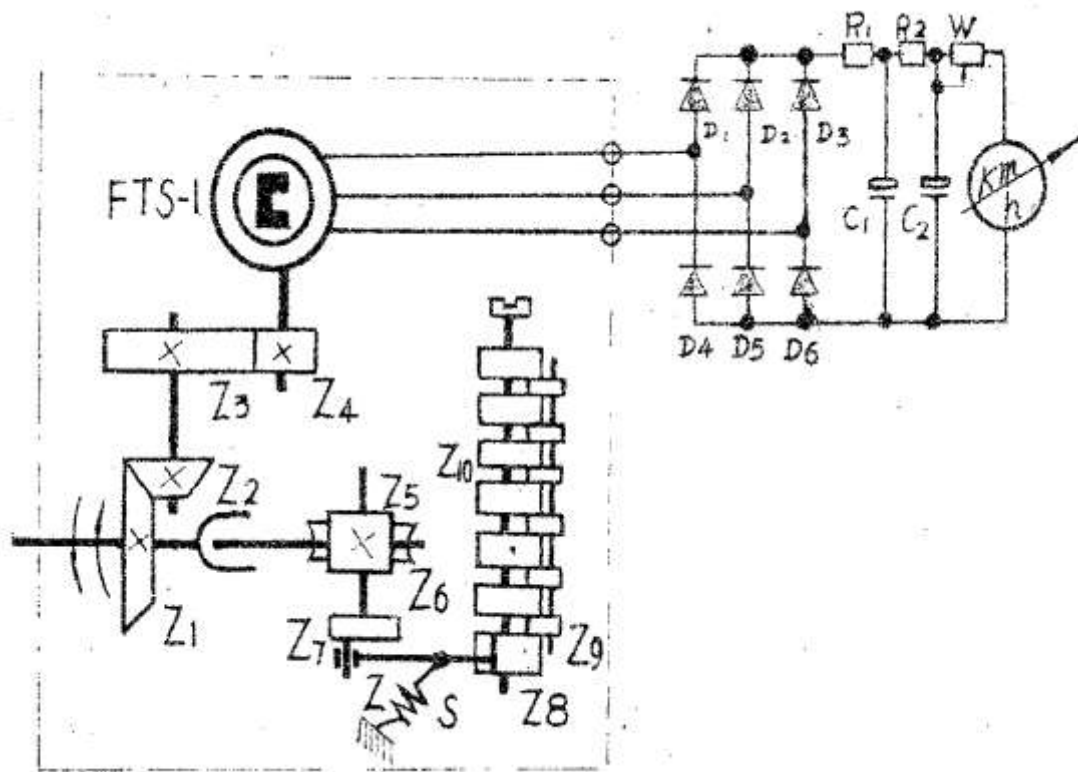


Figure 2.13: Mechanical driving and electrical operating principle of the speedometer
(Source: Dong F.H., 1974)

FTS - 1	Tachogenerator	Z ₁ Z ₂	Bevel gears
Z ₃ Z ₄	Gears	Z ₅ Z ₆	Worm and Gear
Z ₇	Eccentric wheel	Z	Push rod
S	Spring	Z ₈	Ratchet wheel
Z ₉	Feed wheel	Z ₁₀	Digit Wheel
D ₁₋₆	Rectifier Diode	R ₁₋₂	Resistors
C ₁₋₂	Electrolytic capacitors		
W	Potentiometers		km/h milli-ammeter

When the locomotive travels the axle drives the FTS 3- phase, a.c. tachometer generator through gears Z₁Z₂Z₃Z₄, the output voltage of tachogenerator is proportional to the wheel speed. The

output a.c. voltage rectified by 3-phase full wave rectifier and passed through a filter circuit composed of RC components, and connected to the electric magnetic mA meter, which is graduated in wheel flange speed, thus the meter indication equals to travelling speed of locomotive. At the same time, the rotating wheel drives the push rod on the eccentric wheel through the worm and gear Z_5 , Z_6 pushes the ratchet wheel Z_8 , feed wheel Z_9 and digit wheel Z_{10} that counts the mileage accumulated (Dong F. H. 1974)

2.6.1 FUNCTIONS OF SPEEDOMETER SYSTEM COMPONENTS

- Rectifier and filter circuit (RC): It is composed of six 2AP17 diodes, 3-phase full-wave rectifier circuit; it converts the a.c. signal from tachogenerator into d.c. signal. The RC. Filter smoothes off the ripple of pulsating d.c. voltage, thus the meter indication shall be stable at low travelling speed.
- Illumination light: A 5W bulb is used for meter scale illumination with a voltage of 12 volts
- Connecting cord: The meter and transducer is connected by a connecting cord. The cord for tachogenerator is a 3-core cord, while for meter scale illumination is a 2-core cord.
- Driving mechanism: The transducer used is an external mounting type; it is mounted on the axle box cover. The driving shaft is connected flexibly to the locomotive axle through the square shank. It increases the tachogenerator speed 5 times through bevel gears $Z_1.Z_2 = 48:24$ and gears $Z_3:Z_4=50:20$. Step-up of tachogenerator speed is to keep the meter indicating pointer stable when the travel speed is low.
- Tachogenerator: Type FTS-1 permanent magnet 3-phase a.c. tacho-generator is characterized by: 4-pole permanent magnet rotor, Y connected stator windings, rated speed 5000 rpm, rated output between wires 30 ± 0.5 volts, insulation grade E, sustaining a 500 volt test voltage for one minute without break-down, insulation resistance 100 M Ω at 500 volt test voltage.
- Mileage counter: Mileage counter is composed of speed reduction ratchet mechanism and a total distance travelled counter.

Rotation of locomotive wheels drives the eccentric wheel through coupling, worm gear, reducing the speed and the push rod moving back and forth, pushing the ratchet wheel forward, which in turn pushes the digit wheels in a transmission ratio of 10:1 step by step, thus completing the whole operation of total mileage counter.

Choosing of worm gear teeth number depends on the wheel diameter. Worm gear teeth for a large wheel are less than those for small wheels, the reverse is the same. When the locomotive wheel diameter is 915 mm (new design), then the worm gear teeth number shall be 36, i.e. for every 36 wheel turns, the worm rotates one turn, push rod pushes the ratchet wheel forward one step, which is equivalent to 0.1 km distance travelled. For every turn of the ratchet wheel the first digit wheel turns one step, representing 1 km locomotive travelled distance. The maximum kilometres are 999,999km, which will be reset to zero automatically when the mileage reaches this value. If we want to reset the mileage counter to zero in case of intermediate repairing, turn the digit wheel axis with a screw driver in a reverse direction so that all the digits line up and restoring to initial position (Dong F. H., 1974)

The transmission through eccentric wheel push rod and ratchet wheel works the same in both directions so that the mileage counter accumulates both the distances travelled forward as well as backward.

2.7 ADDITIONAL CONCEPTS FOR CONSIDERATION DURING REDESIGNING.

2.7.1 MOUNTING OF METER AND TRANSDUCER

The meter is mounted on the driver's desk, so the driver can easily look at the meter scale. The connecting cord of meter should be tightly connected with locking nuts and carefully protected, and it should not in any case be impaired or stained by grease. When mounting the transducer, the connection of transmission axis of transducer with wheel axle must be reliable. The transducers mounted on axle box are impaired or stained by rains, storms, grease, sand and dust, so it must be well protected by the leather case, with lead wire joint carefully wrapped in a

case to prevent any leakage of water into tachogenerator. Any short circuit will render the meter pointer to swing in a wide range (Dong F. H., 1974).

2.7.2 CLEANING OF MILEAGE COUNTER

Inspect the parts and replace those seriously worn. During assembly, the worm and worm gear are lubricated with some grease. The digit wheels and rotating parts are oiled with few drops of clock oil. Adjust the position of push rod and pawl according to the following figure (Shanghai, 1976). Figure 2.14 provides the relative position of the pushrod and ratchet wheel in the mileage counter.

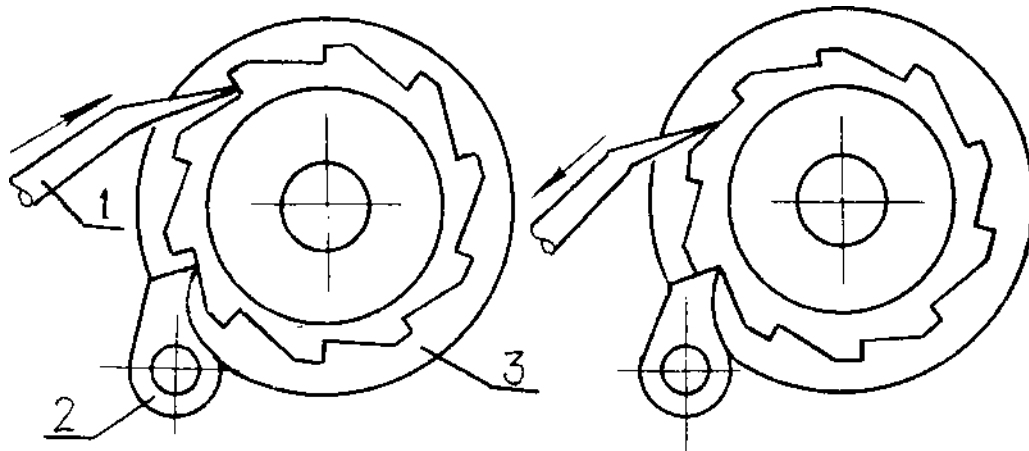


Figure 2.14: Relative Position of Pushrod and Ratchet Wheel
(Source: Dong F.H.,1974)

Sometimes it is required to drive two meters with one transducer. In this case two meters must be calibrated with one transducer on the test stand with their potentiometer adjusted so that two meters will have the same indication. Appendix D provides a detailed mechanical description of an odometer (mileage counter), potential causes of problems and their calibration.

2.7.3 ERROR AND SOURCES OF ERROR

Most speedometers have tolerances mainly due to variations in wheel diameter. Sources of error are due to tyre variations, wear, temperature, pressure, vehicle load and nominal tyre size.

Vehicle manufacturers usually calibrate speedometers to read high by an amount equal to the average error to ensure that their speedometers never indicate a lower speed than the actual travel speed and to ensure that they are not liable for drivers violating speed limits (Hansard, 2001).

Excessive speedometer error after manufacture can come from several causes but most commonly are due to non-standard wheel diameter in which case the error is:

$$\text{Percentage error} = 100 \times (1 - \text{new diameter} / \text{standard diameter}) \quad (2.3)$$

2.7.4 STABILITY IN THE METER INDICATING POINTER

The research by Shanghai Telecommunication Equipment Factory (1979) was aimed at predicting the effect of stepping up the tacho-generator speed. The driving shaft was connected flexibly to the locomotive axle through the square shank. The results revealed that this increased the tachogenerator speed five times through gears. The results also indicated that step-up of tachogenerator speed kept the meter indicating pointer stable when the travel speed was low.

2.7.5 NUMBER OF WORM GEAR TEETH

According to research by Shanghai Telecommunication Equipment Factory (1979) on the choice of the worm gear teeth number, the study indicated that choosing of worm gear teeth number depended on the wheel diameter. The number of worm gear teeth for large wheel was less than those for small wheels. For the new design, the locomotive wheel diameter on average was 900 mm, then it was found that the worm gear teeth number was 36, i.e. for every 36 wheel turns, the worm rotates one turn, push rod pushes the ratchet wheel forward one step, which is equivalent to 0.1 km distance travelled. Further, Appendix E provides guidance in the determination of new odometer (mileage counter) gear teeth number. Figure 3.15 shows a worm gear.



Figure 2.15: Worm gear

2.7.6 WHEEL DIAMETER AND TRAVEL SPEED

The indicating meter and transducer are to be checked in pair on the speedometer test stand. Speedometers from the factory are regulated according to the new wheel diameter. Should the meter indication differ from actual speed, the accuracy shall be regained if the potentiometer was adjusted (Rhodes A., 2000).

2.7.7 CONNECTION OF TRANSDUCER WITH WHEEL AXLE

According to Christian Albert (2012), when mounting the transducer, the connection of transmission axis of transducer with wheel axle must be reliable. This enabled the tachogenerator shaft to rotate freely.

2.7.8 LOW OR NO SPEED INDICATION OF SPEEDOMETER

Low or no speed indication of speedometer were caused and remedied as indicated below.

Causes:

- i. Poor contact of Connector;
- ii. Broken wire, short circuit and de-magnetisation of tacho-generator;
- iii. Short circuit or open circuit of rectifier diodes;
- iv. Fall off of gear pin of generator shaft;

- v. Rounding off of square shank of transmission shaft; and
- vi. Damped connector.

Remedies

- i. Check the connection of wire and contact of connector;
- ii. Check the diode and the soldered joints of resistors and capacitors;
- iii. Check the reliability of transmission and put it in order;
- iv. The demagnetisation may be compensated by re-adjusting the potentiometer; and
- v. The meter pointer cannot restore to null point of sticking. This is caused by:
 - Meter pointer is choked
 - The spiral spring being out of order
 - Worn pivot point zero adjusting lever displaced

2.8 GENERAL INSTRUMENT CALIBRATION

Calibration involves ascertaining and documenting deviation of the measured value from a retraceable, highly accurate test standard. The measured value obtained from a measuring instrument is thus compared with the known value of the test standard under specified reference conditions using reproducible measuring procedures. Calibration does not involve any manipulation of the measuring instrument, which remains entirely unchanged.

Adjustment involves the correction or balancing of a measuring instrument in order to eliminate systematic measurement deviation. The measured value obtained from a measuring instrument is thus adjusted to match the known value of the test standard under specified reference conditions. Adjustment always involves manipulation, which permanently changes the measuring instrument. (Rhodes, 2000).

2.8.1 ZERO AND SPAN ADJUSTMENT (ANALOG INSTRUMENTS)

The purpose of calibrating is to ensure that the input and output data of an instrument corresponds to each another predictably throughout the entire range of operation. This expectation may be expressed in the form of a graph. Figure 3.16 shows how the input and output of an instrument should relate.

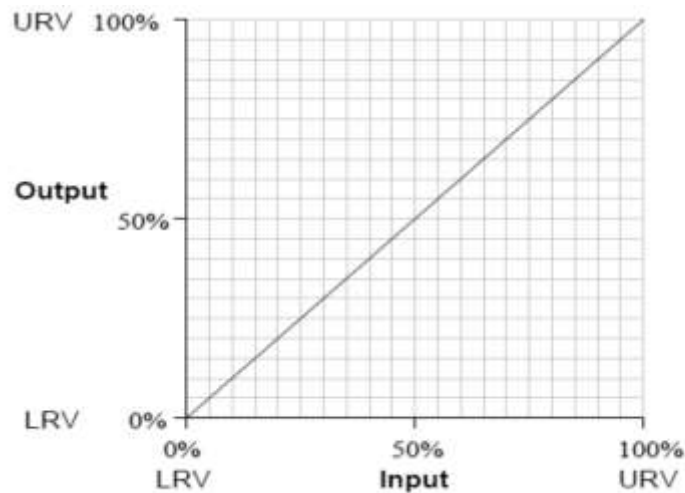


Figure 2.16: showing how the input and output of an instrument should relate

Figure 3.16 shows how any given percentage of input should correspond to the same percentage of output, all the way from 0% to 100%.

Things become more complicated when the input and output axes are represented by units of measurement other than “percent”. Take for instance a pressure transmitter, a device designed to sense a fluid pressure and output an electronic signal corresponding to that pressure. Figure 3.17 shows a graph for a pressure transmitter with input range of 0 to 100 pounds per square inch (psi) and an electronic output signal range of 4 to 20 milliamps (Ma) electric current:

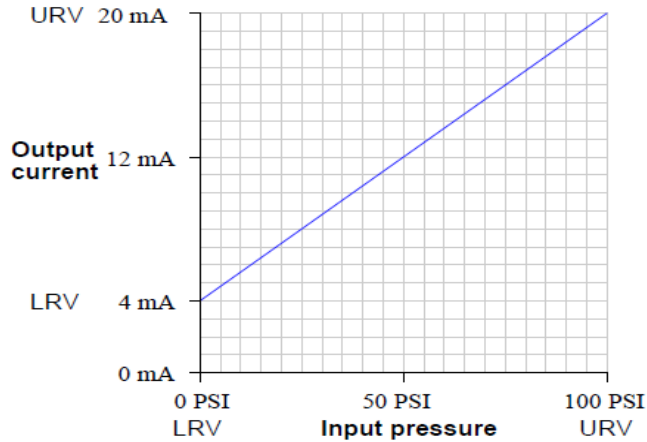


Figure 2.17: Graph indicating input and output of a Pressure Transmitter

Although the graph is still linear, zero pressure does not equate to zero current. This is called a line zero, because the 0% point of measurement (0 psi fluid pressure) corresponds to a non-zero (“live”) electronic signal. 0 psi pressure may be the lower range value (LRV) of the transmitter’s input, but the LRV of the transmitter’s output is 4 mA, not 0 mA.

Any linear, mathematical function may be expressed in “slope-intercept equation form:

$$y = mx + b \quad (2.4)$$

Where:

- y = vertical position of the graph
- x = horizontal position of the graph
- m = slope of the line
- b = point of intersection between the line and the vertical (y) axis.

This instrument calibration is no different. If x represents the input pressure in units of psi and y represents the output current in units of milliamps, an equation for this instrument may be written as follows:

$$y = 0.16x + 4 \quad (2.5)$$

On the actual instrument (the pressure transmitter), there are two adjustments which let us match the instrument's behaviour to the ideal equation. One adjustment is called the zero while the other is called the span. These two adjustments correspond exactly to the b and m terms of the linear function, respectively: the "zero" adjustment shifts the instrument's function vertically on the graph, while the "span" adjustment changes the slope of the function on the graph. By adjusting both zero and span, the instrument may be set for any range of measurement within the manufacturer's limits.

The relation of the slope-intercept line equation to an instrument's zero and span adjustments reveals something about how these adjustments are actually achieved in any instrument. A "zero" adjustment is always achieved by adding or subtracting some quantity, just like the y -intercept term b adds or subtracts to the product mix. A span adjustment is always achieved by multiplying or dividing some quantity, just like slope m forms a product with the input variable x .

It should be noted that for most analogy instruments, zero and span adjustments are interactive. That is, adjusting one has an effect on the other. Specifically, changes made to the span adjustment almost always alter the instrument's zero point. An instrument with interactive zero and span adjustments requires much more effort to accurately calibrate, as one must switch back and forth between the lower and upper-range points repeatedly to adjust for accuracy.

2.8.2 SPEEDOMETER ACCURACY AND CALIBRATION

No speedometer can be 100% accurate. In fact, most manufacturers build speedometers so they fall within a fairly narrow tolerance range. As long as a vehicle is maintained at factory specs, its speedometer should continue to register speed within these specs. But if a vehicle is modified, its speedometer may need to be re-calibrated.

All speedometers must be calibrated to make sure the torque created by the magnetic field accurately reflects the speed of the vehicle. Calibration must take into account several factors, including the ratios of the gears in the drive cable, the final drive ratio in the differential and the diameter of the tyres. All these factors affect the overall speed of the vehicle. Take tyre size, for

example, when an axle makes one complete turn, the tyre it is connected to makes one complete revolution. But a tyre with a larger diameter will travel further than a wheel with a smaller diameter. That is because the distance a tyre covers in one revolution is equal to its circumference.

Calibration adjusts these variances and is done by the manufacturer, which sets up the speedometer gear to correspond with the factory-installed ring and pinion ratio and tyre size. There will be need to recalibrate the speedometer if changes are made that makes a vehicle fall out of factory specifications. Recalibrating a speedometer can be done by manipulating the hairspring, the permanent magnet or both. Generally, the strength of the magnetic field is the easiest variable to change. This requires a powerful electromagnet, which can be used to adjust the strength of the permanent magnet in the speedometer until the needle matches the input from the rotating drive cable. Figures 3.18 and 3.19 show the DFH₂ speedometer gauge and testing stand.



Figure 2.18: DFH₂ Speedometer



Figure 2.19: DFH₂ speedometer Testing Stand

2.9 DE LOCOMOTIVE RAIL LINE TEST STANDARDS

Whenever a locomotive is due to undergo scheduled maintenance or repair, among other things, the diameter of its wheel sets are thoroughly inspected, measured and recorded. The wheel set connected to the speedometer system, if found to be below the acceptable limits, it is replaced with another. This calls for recalibration of the transducer and the speedometer(s). After undertaking scheduled maintenance the locomotive is subjected to rail line tests to ascertain conformity to performance standards including speedometer system accuracy.

There is a direct relationship between the sentry panel voltage and actual locomotive travel speed. The relationship is defined by the equation 2.6 and Table 2.1.

$$v = V_{SP} \times C \quad (2.6)$$

Where

- v = travel speed in km/h
- V_{SP} = Sentry panel voltage
- C = constant derived by the manufacturer

Table 2.1 provides the DE locomotive standard relationship between v and V_{sp}

Table 2.1: DE locomotive standard relationship between v and V_{sp}

$v(\text{km/h})$	10	20	30	36	40	50	60
V_{SP}	0.83	1.66	2.5	3	3.33	4.16	5

2.10 ANALYSIS OF THE DFH₂ AND DE SPEEDOMETER SYSTEMS

For a DFH₂ speedometer system to be redesigned and applied successfully on DE locomotives, it was imperative to conduct an analysis of the energy conversion process from the DE transmission through the DFH₂ transducer and cable leading to the final DFH₂ speedometer reading that would be equivalent to that of the DE standard speedometer output.

It was also cardinal to systematically determine parts for redesigning or adjustment. Interaction of parts, measurements, manufacturing process requirements, cost considerations, laboratory calibration and railway line tests were factors used to determine parts for adjustment or redesigning. The critical components of a speedometer system for analysis were as follows: the speedometer gauge and mileage counter; tachogenerator, tachogenerator drive shaft; journal box cover, fork assembly, wheel diameter, circular plate and the after-effects of applying the components of the DFH₂ speedometer system on the DE system.

2.10.1 ANALYSIS OF THE ENERGY CONVERSION PROCESS AND SPEEDOMETER READINGS

2.10.2 DE AND DFH₂ SPEEDOMETER SYSTEM OUTPUTS

- i. For the DFH₂ system:

Let $P_1 =$ Power input to the DFH₂ transducer
 $P_2 =$ Power output from the DFH₂ transducer
 $V_1 =$ DFH₂ input voltage
 $I_1 =$ DFH₂ input current

$V_2 =$ DFH₂ tachogenerator output voltage
 $I_2 =$ DFH₂ tachogenerator output current
 $V_{dfh} =$ DFH₂ speedometer reading

Therefore, $P_2 = V_2 \times I_2$ (2.7)

From section 2.6: V_2 is directly proportional to V_{dfh}

ii. For the DE system:

Let $V_{sp} =$ Sentry Panel voltage
 $V_{de} =$ DE locomotive standard speedometer reading as in table 2.1
 $V_3 =$ DE tachogenerator output voltage

From section 2.9: V_3 is directly proportional to V_{de} and V_{sp}

Therefore, $V_3 = C \times V_{sp}$ (2.8)

where C is a constant.

For $V_{dfh} = V_{de}$, (2.9)

Then $V_2 = V_3 = V_{sp}$

But since V_3 cannot be measured due to the absence of the DE tachogenerator, V_{sp} is measured (in accordance with Table 2.1) from the DE locomotive sentry panel using a voltmeter and compared to the DFH₂ speedometer readings. This is done as the DE locomotive is in motion.

Since the DE locomotive would be in motion, it would equally be difficult to measure the DFH₂ tachogenerator output voltage (V_2). Therefore, V_2 can either be read from the DE locomotive voltmeter on the dash board or the DFH₂ speedometer readings (V_{dfh}) can be recorded as the locomotive is moving and related to the V_{sp} in Table 2.1. If the relationship between V_{dfh} and V_{sp} satisfies equation 2.6 and Table 2.1, then the objectives of redesigning to achieve standard DE speeds are fulfilled.

CHAPTER 3
MATERIALS AND METHODOLOGY

3.1 INTRODUCTION

This chapter presents steps undertaken in the speedometer development process and justifications for adopting certain decisions and methods of manufacturing or adjustment of particular parts. The speedometer system development followed the procedure outlined in the Figure 3.1.

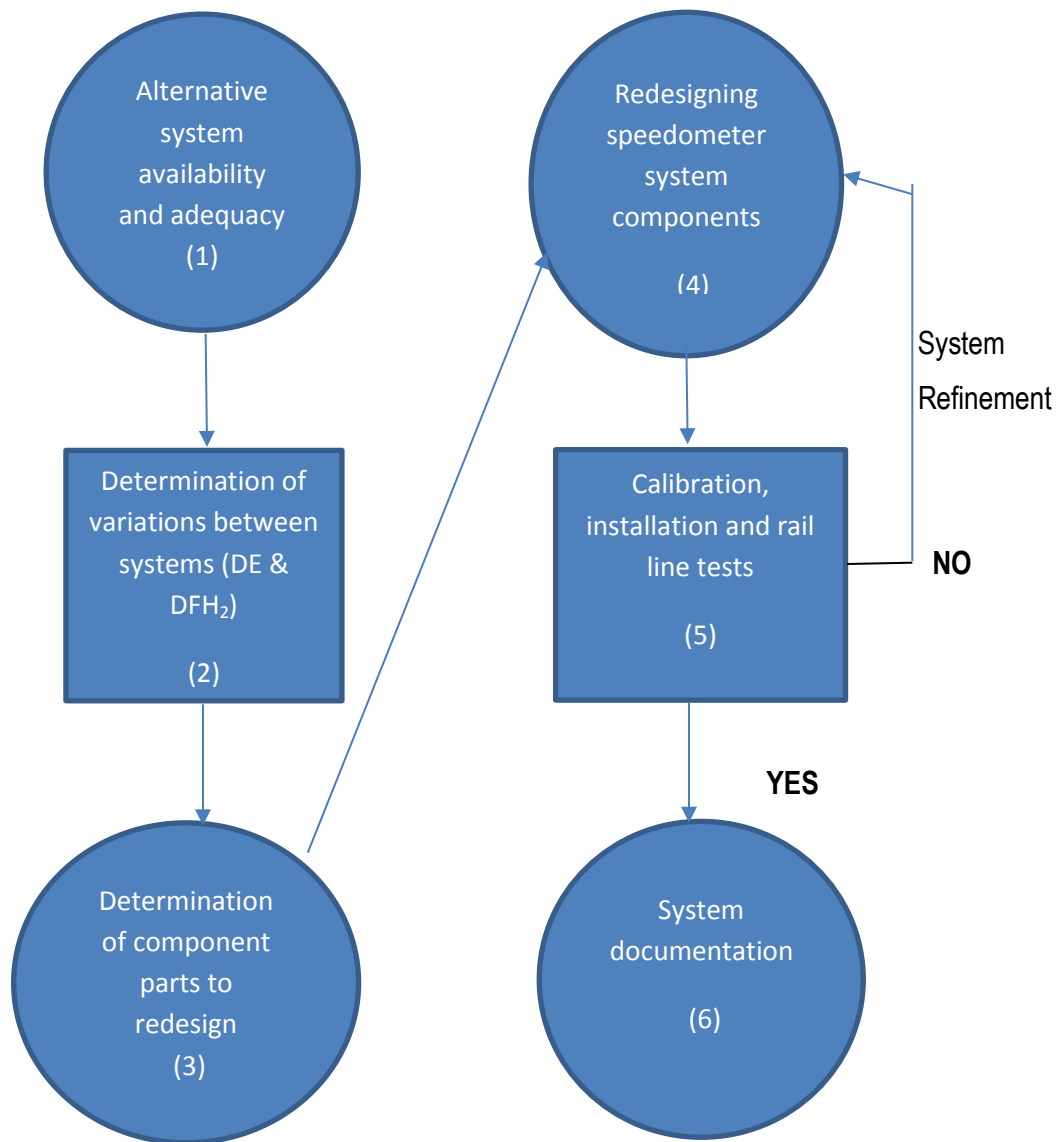


Figure 3.1: *Speedometer development process.*

3.2 ALTERNATIVE SPEEDOMETER SYSTEM AVAILABILITY AND ADEQUACY

TAZARA has used four types of main line locomotives since its inception: Dong Fang Hong (DFH₂), Repowered MTU, Diesel Electric (DE) and the Dalian. Before handover in 1975, the Government of the People's Republic of China brought among others a lot of DFH₂ speedometer system backup spares for the DFH₂ locomotives which were still lying in stores. TAZARA only bought four (4) units of the Dalian locomotives and therefore, very few speedometer system spares were supplied. TAZARA encountered several technical hardships with the DFH₂ engines and as a result decided to buy MTU engines which were installed in the DFH₂ shells. Therefore, the speedometer system for the repowered MTU and DFH₂ is the same. Most DE locomotives did not have an operational speedometer system and there were no back up spares in the stores.

The cost of buying a new DE speedometer system (\$3,800) is almost the same as that of buying the Dalian locomotive speedometer system. Therefore, considering that there were abundant DFH₂ speedometer system components in stores, it became economical to redesign the DFH₂ system than buying new and expensive DE speedometer system.

3.3 DETERMINATION OF VARIATIONS BETWEEN THE TWO SPEEDOMETER SYSTEM COMPONENTS (DFH₂ AND DE SYSTEMS)

3.3.1 INTERACTION OF PARTS IN THE DFH₂ AND DE LOCOMOTIVE SPEEDOMETER SYSTEMS.

In order to ensure an orderly and systematic final assembly of the DFH₂ based speedometer system, visual inspections were undertaken on both types of locomotive speedometer systems to ascertain how parts were mounted and connected to each other. During the visual inspection exercise, sketches of the two speedometer systems were made.

3.3.1.1 DFH₂ SYSTEM

One defective DFH₂ locomotive packed in TAZARA Mpika workshops had an serviceable speedometer system and was used for assessing the DFH₂ speedometer system. Considering that the DFH₂ speedometer gauge was linked to the transducer by means of a three core cable, it became necessary to begin with the assessment of how the transducer was linked to the locomotive wheel axle. Since the transducer is mounted on the journal box cover, it was difficult to see how the transducer drive shaft is connected to the wheel axle. Therefore, it became necessary to remove both the transducer and journal box cover as shown in the Figure 3.2.



Figure 3.2: DFH₂ Journal box

After removing the two, the transducer was thereafter deliberately connected to the fork assembly to establish the nature of the internal assembly and a sketch of the interaction of parts was made as shown in Figures 3.3 and 3.4 to aid future assembly of the final speedometer system. The transducer shell is attached to the journal box cover by means of four bolts and nuts. The transducer drive shaft is connected to the locomotive wheel axle by means of a square fork assembly. The fork assembly is connected to a circular plate by means of a pin, and split pin. The circular plate is connected to wheel axle by means of three bolts. Figure 3.3 shows the Connection of DFH₂ transducer to wheel axle after removal of journal box cover. Figure 3.4

shows the sketch of the front view of a DFH₂ Circular plate with a drive shaft. Figure 3.5 shows the side and front view of a DFH₂ fork assembly.

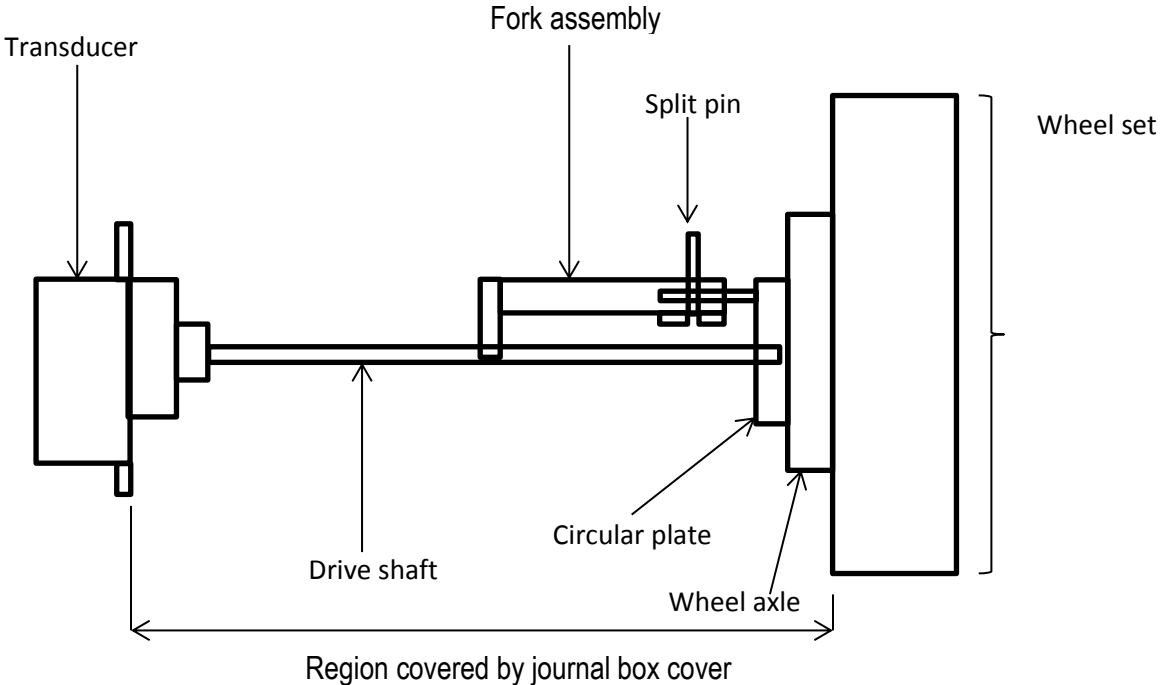


Figure 3.3: Connection of DFH₂ transducer to wheel axle after removal of journal box cover.

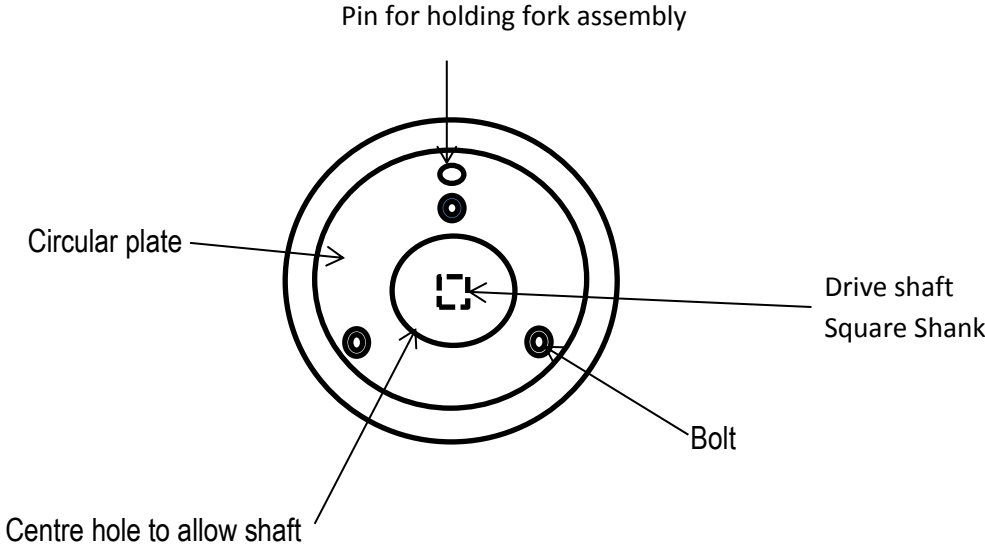


Figure 3.4: Front view of a DFH₂ Circular plate with a drive shaft

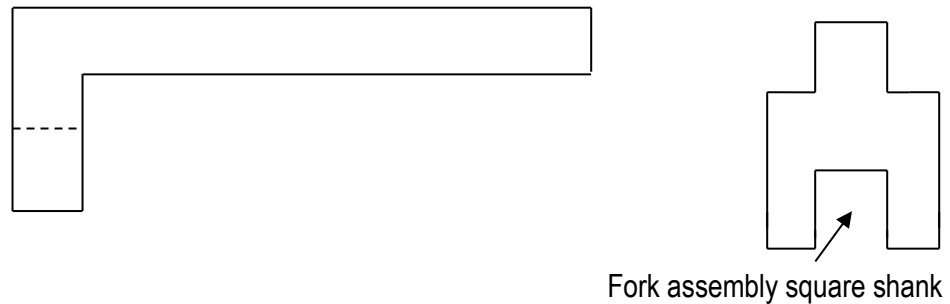


Figure 3.5: *Side and front view of a DFH₂ fork assembly.*

3.3.1.2 DE SYSTEM

The DE locomotives are only repaired and serviced at Mbeya TAZARA workshop in Tanzania. Although one DE locomotive number 1027 was provided for the project, it did not have a speedometer system. It only had cables, journal box cover and circular plate of the speedometer system. The following procedure was adopted in order to determine the interaction, dimensions and geometry of the DE speedometer system component parts:

- a. The DE speedometer system cables were long enough to be used for the proposed DFH₂ system and therefore, there was no need to measure them;
- b. The DE locomotive number 1027 was shunted in the locomotive maintenance shop, lifted using hydraulic jacks, bogie removed and a locomotive was finally lowered to sit on a dummy bogie (temporal bogie). Figure 3.6 shows a DE locomotive suspended on lifting jacks.



Figure 3.6: *DE locomotive suspended on lifting jacks*

- c. After cleaning the mono block tyre tread, the diameter of the mono block connected to the speedometer system was measured using a calibrated wheel diameter gauge. After measuring the wheel diameter the locomotive was lowered on its bogie. Figure 3.7 shows a DE locomotive wheel set.

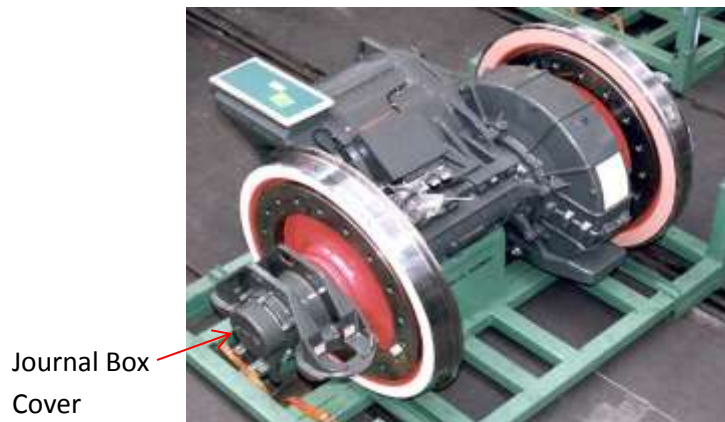


Figure 3.7: *DE locomotive wheel set*

- d. The physical interaction of parts was done on another DE locomotive that was shopped in briefly for casual repairs and sketches were made based on the observed physical interaction. Figure 3.8 shows the Connection of the DE transducer to wheel axle after removal of journal box cover.

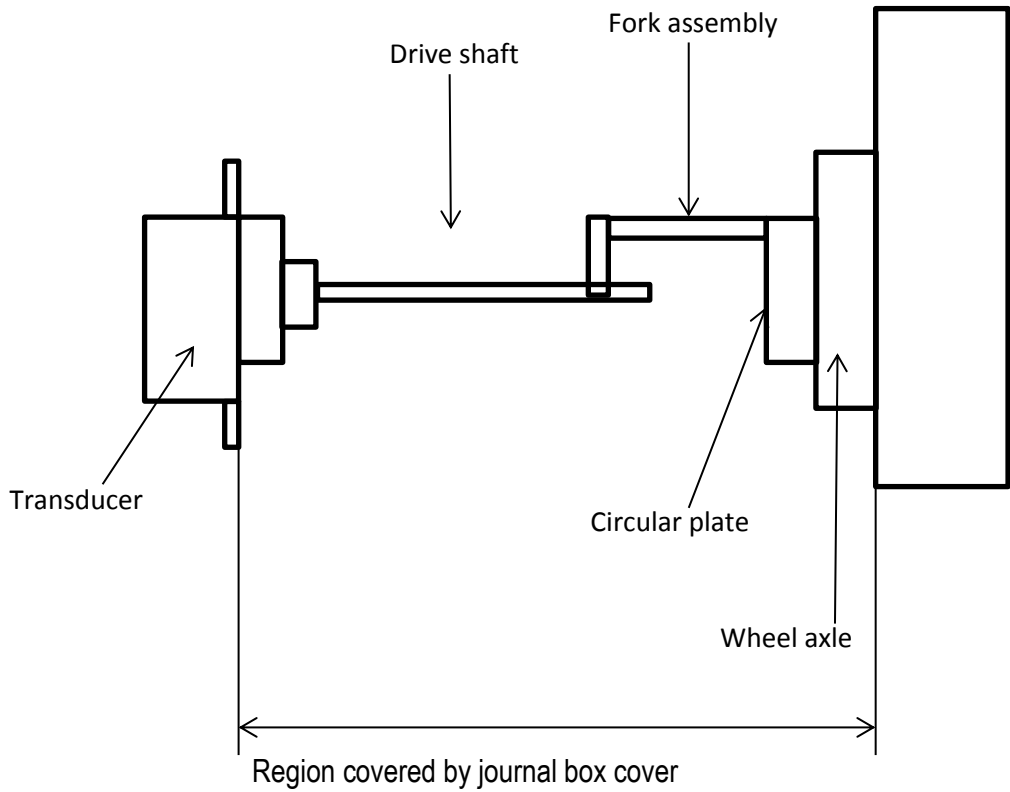
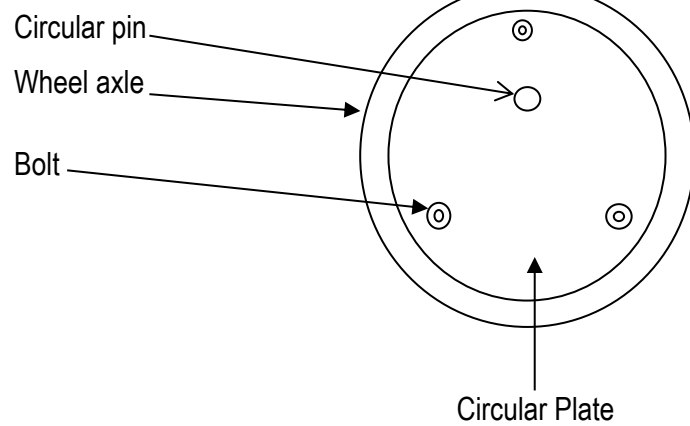


Figure 3.8: Connection of DE transducer to wheel axle after removal of journal box cover.

i) Front View:



ii) Side view:

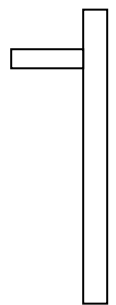


Figure 3.9: Front and side views of the DE Circular plate

3.4 MEASUREMENTS

3.4.1 DISMANTLING OF DE AND DFH₂ SPEEDOMETER SYSTEM COMPONENTS

Lubricating oils and tools which include screw drivers, spanners of various sizes were employed for softening and untying of bolts and nuts that held speedometer system components from their respective locomotives.

3.4.2 CLEANING OF COMPONENTS

The transducer shell, drive shaft, fork assembly, circular plate and its pin were washed thoroughly in petrol to remove the dirt. Petrol was chosen in preference to kerosene as it dried faster and was readily available in the workshops.

3.4.3 SURFACE PLATE

Before taking measurements, all the speedometer system parts from the DE and DFH₂ locomotives were wiped with a clean mutton cloth to ensure they were dust-free. All the speedometer system parts were placed and measured from a surface plate to ensure accuracy of measurements. The parts were measured in the following sequence:

I. Transducer Shell and Circular Plate

Calibrated vernier Calliper and micrometer screw gauge were used to measure the diameters and thickness of the transducer and circular plates of the DE and DFH₂ locomotives.

II. Transducer Drive Shaft

A calibrated vernier calliper was used to measure the length, diameter and width of the drive shafts (DE and DFH₂).

III. Wheel Diameter

The wheel diameters of both locomotive numbers DE 1027 and DFH₂ 092 were measured using a wheel diameter gauge.

IV. Speedometer Gauge

The DFH₂ speedometer gauge was not subjected to measurements as dimensions of its internal and external parts were indicated in the Chinese repair and maintenance manual as given under Section 2.6. It was not easy to get dimensions of a DE speedometer gauge because very few locomotives had them and all such locomotives were too busy in railway operations to be called. It was also important to note that since the DE wheel diameter was measured, issues associated with mileage counter (odometer) components and their associated dimensions were going to be easy.

3.5 COMPARISON OF SPEEDOMETER SYSTEM COMPONENTS

Based on **visual inspections**, the following were observed:

- a. The DE fork assembly was smaller than that of the DFH₂ speedometer system.
- b. The DE circular driving shaft was shorter in length and larger in diameter than the DFH₂ square drive shaft.
- c. The DE circular plate was thinner, and did not have a hole like the DFH₂ circular plate as shown in Figures 3.4. and 3.9 respectively.
- d. The DE circular pin was shorter and smaller in diameter compared to the one for the DFH₂.

The DE system drive shaft is 110 mm in length and circular in shape with a diameter of 20 mm. The DFH₂ system drive shaft is 170 mm in length and square in shape with a width of 15 mm. The variation in the drive shaft lengths is 60 mm.

The DE speedometer system wheel diameter is 900 mm. The DFH₂ speedometer system wheel diameter is 915 mm. The difference between the two speedometer system wheel diameters is 15mm. Table 3.1 below shows the DE and DFH₂ system components and their dimensions.

Table 3.1: DE and DFH₂ Speedometer System Components and their Dimensions

<i>Speedometer Components</i>		<i>DE Locomotive (mm)</i>	<i>DFH₂ Locomotive (mm)</i>	<i>Variation (mm)</i>
<i>Transducer Drive Shaft Length</i>		110	170	60
<i>Wheel Diameter</i>		900	915	15
<i>Circular Plate Thickness</i>		3	4	1

3.6 DETERMINATION OF COMPONENT PARTS TO REDESIGN.

First and foremost, availability of spare parts was a paramount consideration for a particular speedometer system sustainability and because the DFH₂ system parts were in abundance, the inclination was towards redesigning or adjusting the DFH₂ system parts. In terms of design and assembly, the DFH₂ system corresponds to type 1R (C) 2RC (P) transducer with an exception that the DFH₂ drive shaft was squared.

Some parts such as the DFH₂ transducer drive shaft were heat treated and for them to be adjusted by means of machining, the need to soften them would have risen. This heat treatment process would have been costly not to mention complications involved in dismantling the drive shaft from inside of the transducer shell. Additionally, according to the principle under Section 2.5.1, due to the characteristics of the permanent magnets used, magnets become partially

demagnetized and then the tachogenerator would not supply the voltage rated value. Arising from the principle, it was resolved to maintain the DFH₂ transducer drive shaft length.

The manufacturing process and resources availability were equally considered. Pattern, Forge, Foundry, Fabrication and Machining Shops were available for making new components and adjusting the existing parts. Materials such as sheet metal or plates were in abundance from scrapped rolling stock (R/S).

Concepts and principles governing the use of a particular combination of parts given under Sections 2.8.5, 2.8.6 and 2.8.7 played an important role in the selection of parts for adjustment or redesigning. Taking into account various factors, the following parts were found suitable for redesigning, adjustment or introduction:

- a. Circular Plate Thickness, its features and relationship with the drive shaft;
- b. Mileage Counter Worm Gear;
- c. Wheel Diameter (for configuration of mileage counter);
- d. Speedometer Fork Assembly;
- e. DE Journal Box Cover; and
- f. Transducer Bracket.

After determining variations in the systems parts and consideration of given principles, focus was put on the transducer drive shaft, circular plate, fork assembly, wheel diameter, journal box cover, cow-cature (locomotive bumper) and wheel axle holes for bolts (for holding circular plate). To accomplish this, several factors were considered as follows:

- a. Transducer drive shafts

The DFH₂ square drive shaft was longer and its width smaller compared to the DE drive shaft that is shorter and circular with a diameter larger than the width of the DFH₂ drive shaft. The most direct method would have been to reduce the length of the DFH₂ drive shaft but its width was smaller than the diameter of the DE circular drive shaft. Machining another drive shaft was another option but considering the principle under Section 2.5.1, assembly requirements

supplemented by cost implications (heat treatment), the option could not suffice. Basing on the aforementioned, it was resolved to maintain the original DFH₂ drive shaft length and width.

b. Circular plate

The major function of the circular plate in both systems is to hold the fork assembly and transmit wheel axle motion to the transducer drive shaft. In the DFH₂ system, the circular plate has a circular hole (whose diameter is larger than drive shaft width) in the middle to allow some length of the drive shaft as indicated in Figures 3.3 and 3.4. The extra length of the drive shaft passing through the circular plate serves no purpose at all. In the DE system the circular plate has no hole in the middle as the drive shaft length is short and does not reach the circular plate as shown in Figures 3.8 and 3.9. The DE circular plate is thinner than the DFH₂ plate.

Based on the nature (steel plate), size of material required for making a circular plate and its availability, a decision was made to make a circular plate with a square shank (width equal to DFH₂ drive shaft width) to allow entry (interference fit) of some DFH₂ drive shaft length. Since the DE circular plate is thinner than that of the DFH₂ system, a decision was made to use the DFH₂ circular plate thickness and after rail line tests results to gradually increase the thickness which also allowed some additional length of the shaft to enter until the principles narrated under Sections 2.7.1 and 2.7.7 were attained. Because the circular plate was held by three bolts and the need to avoid minor peripheral deformation of the plate observed after railway line tests, the shape of the plate was adjusted to become triangular as shown in Figure 3.10.

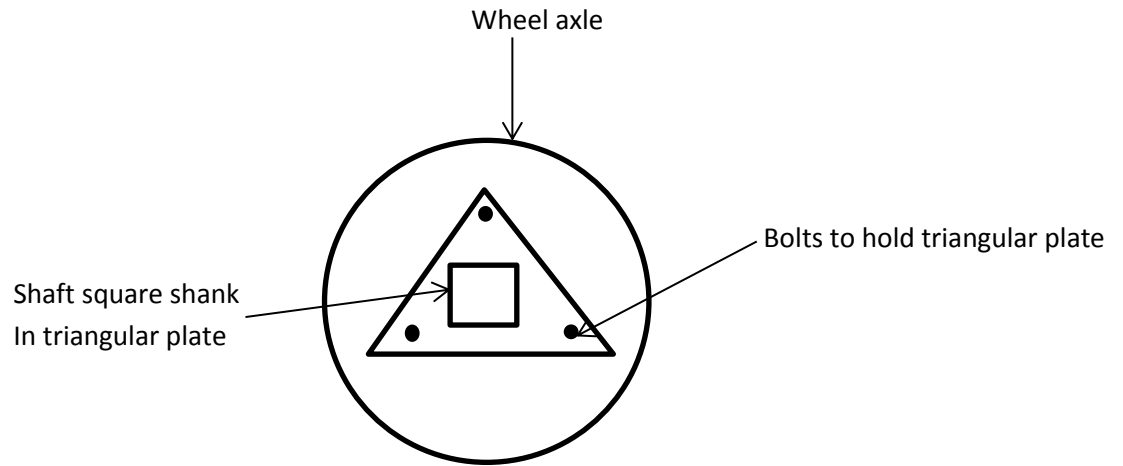


Figure 3.10: Front view of triangular plate connected to DE locomotive wheel axle (Final design)

c. Fork Assembly

In both speedometer systems, the fork assembly connects the drive shaft to the wheel axle. The DE drive shaft diameter is larger than the width of DFH₂ drive shaft and therefore, the DE fork assembly component for holding the drive shaft was equally larger, circular and could not be used for holding the DFH₂ drive shaft. There are no DFH₂ fork assembly components in stores and therefore, a decision was made to get rid of the fork assembly in the new speedometer system. This was also necessitated by the time and cost implications involved in machining or buying a suitable fork assembly. It would cost 32 working hours at K10 per hour to forge a blank and machine the fork assembly costing K320.

Therefore, after doing away with the fork assembly, the final DFH₂ based speedometer system was as shown in the Figure 3.11.

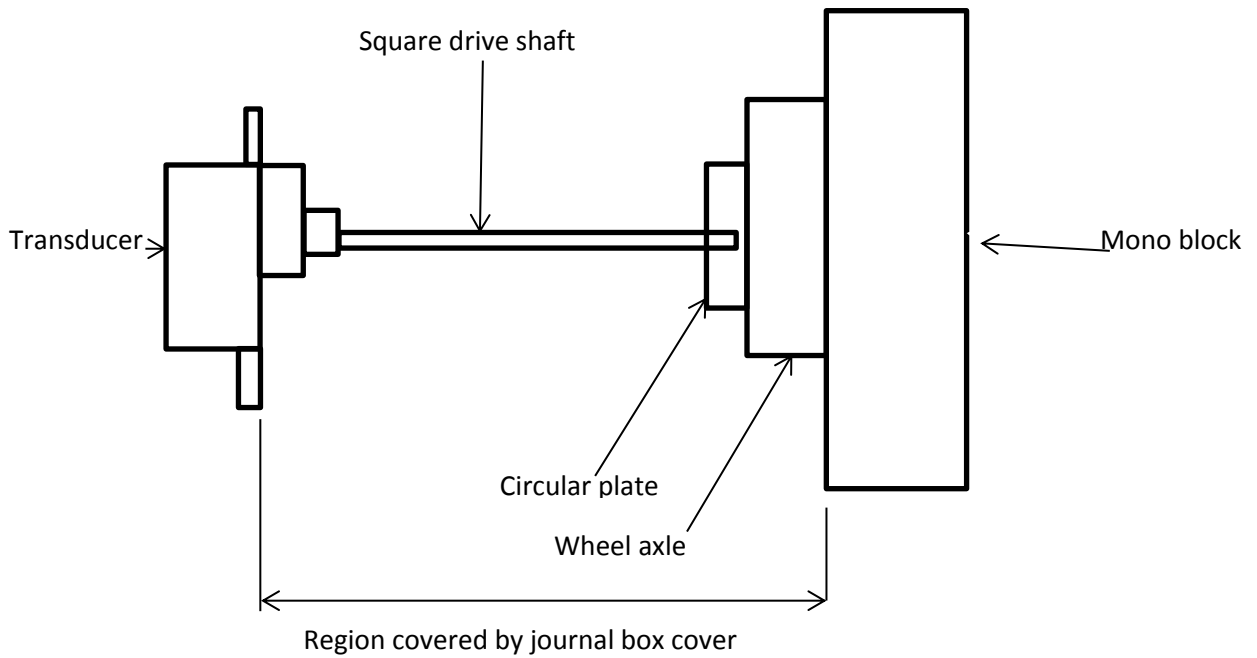


Figure 3.11: Final DFH₂ based speedometer system installed on a DE locomotive number 1027

3.7 PICTORIAL AND ENGINEERING DRAWINGS FOR THE FINAL DFH₂ SPEEDOMETER SYSTEM

The pictorial and engineering drawings of the initial and final DFH₂ based speedometer systems are shown in figures 3.12, 3.13, 3.14, 3.15, 3.16 and 3.17 below.

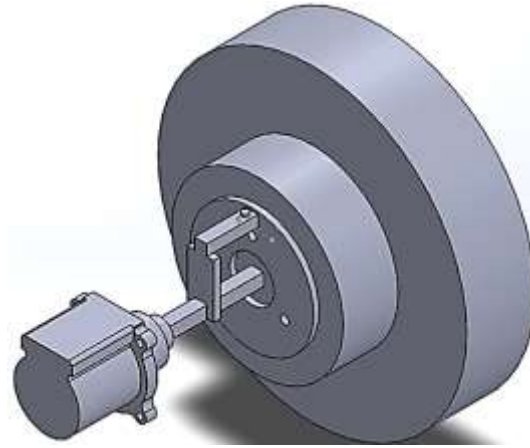


Figure 3.12: Interaction of Parts in the Initial DFH₂ System (Front View)

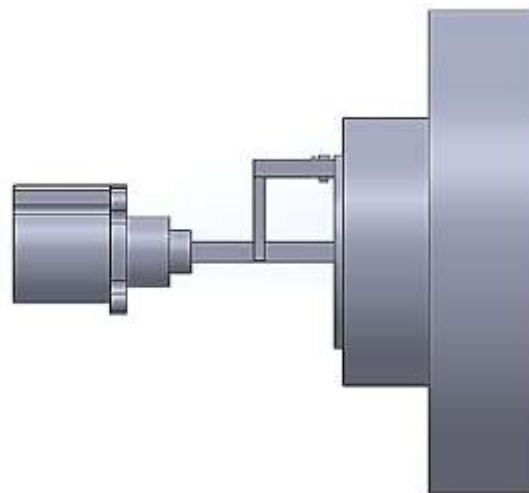


Figure 3.13: Interaction of Parts in the Initial DFH₂ System (Side View)

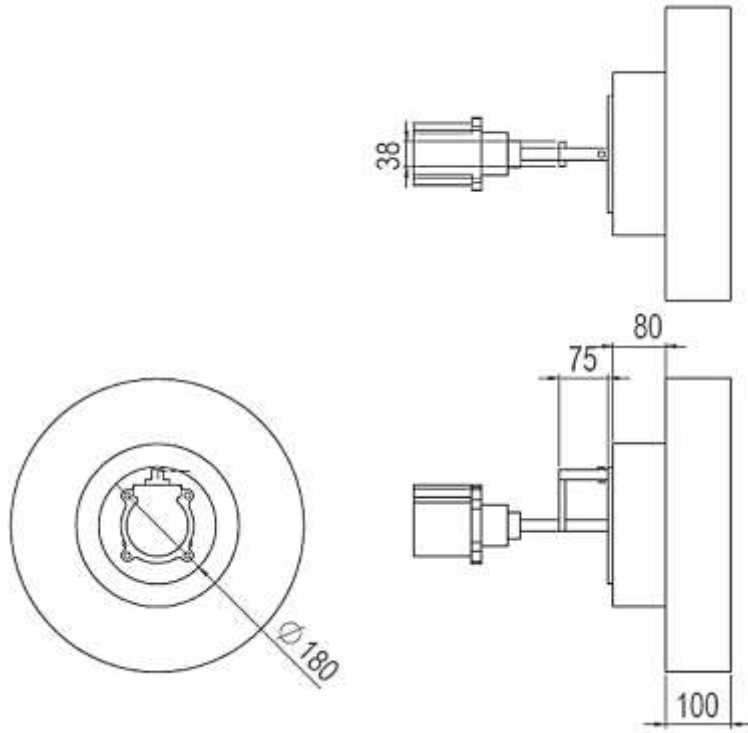


Figure 3.14: Engineering Drawings of the Initial DFH₂ Speedometer System

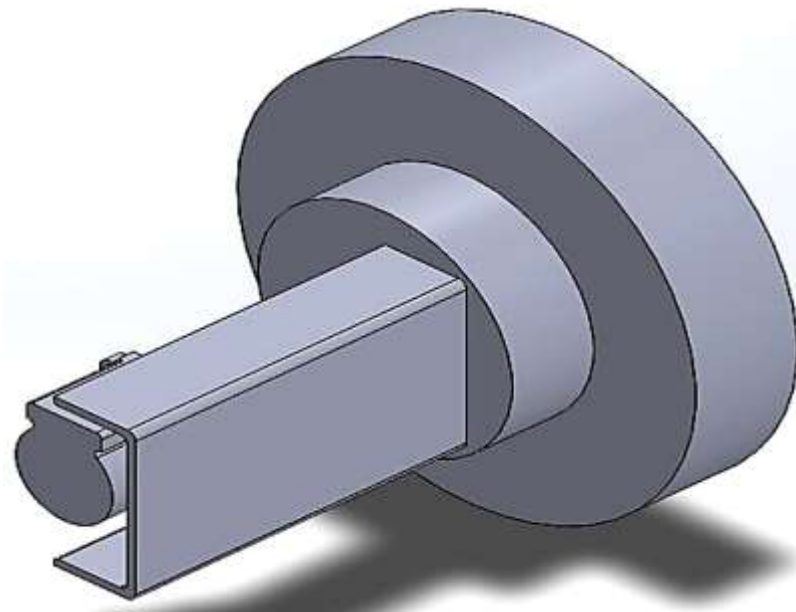


Figure 3.15: Pictorial Drawing of the Final DFH₂ Speedometer System (Front View)

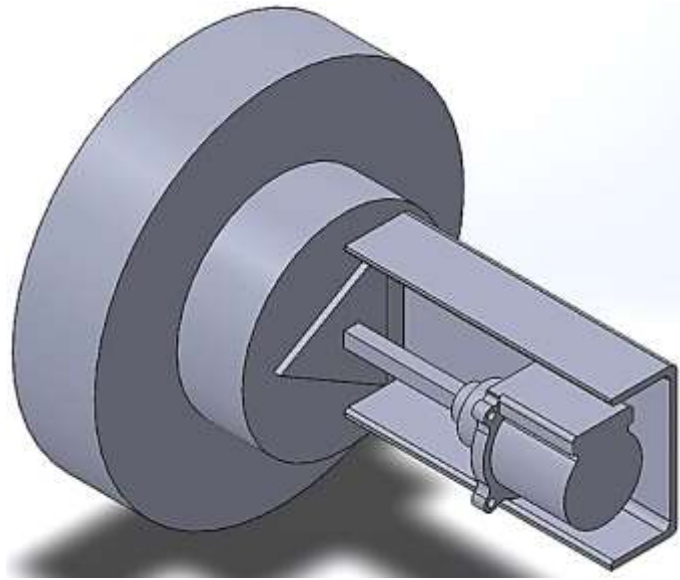


Figure 3.16: Pictorial Drawing of the Final DFH₂ Speedometer System (Side View)

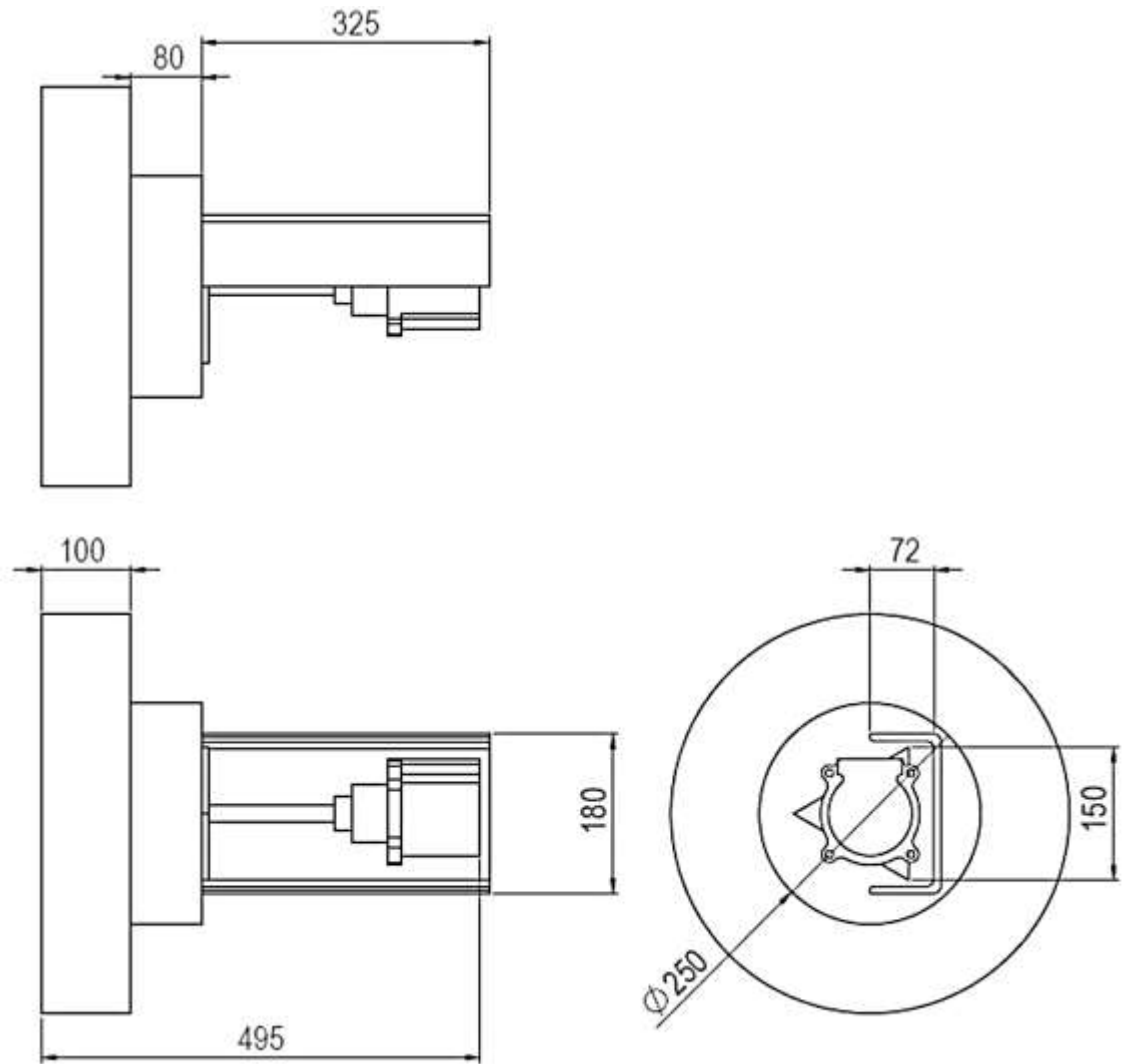


Figure 3.17: Engineering Drawings of the Final DFH₂ Speedometer System

d. Wheel diameter

The diameter of the mono block (wheel) connected to the speedometer system was very important during calibration or matching of the transducer with the speedometer gauge. It was also important in determining the number of worm gear teeth to use in the DFH₂ mileage counter. Since a speedometer gauge for the DE system could not be found, it was resolved to make use of the DE mono block (wheel) diameter to give an indication of the worm gear teeth number required in line with the principle under Section 2.7.5. Therefore, the DFH₂ speedometer gauge

was not opened to count the number of teeth on the worm gear until rail line tests were undertaken and mileage counter (odometer) readings observed.

e. Journal Box Cover

The journal box cover is provided to house the bearings (shield them from dust) and for mounting the transducer. The DE transducer shell is smaller than the DFH₂ transducer shell and therefore, the bolt holes on the DE journal box cover are more closely spaced than those on DFH₂ journal box cover.

Regarding the connection of DFH₂ transducer to the DE wheel axle, two decision options became apparent: to cast other journal box cover or to make use of the DE journal box cover for other wheel sets that were not connected to the speedometer system since they did not have bolt holes for mounting the transducer as indicated in the Figure 3.7. Figure 3.18 shows a DE journal box without a cover.



Holes for mounting journal box cover

Figure 3.18: *DE journal box without cover*

One journal box cover not linked to the speedometer system was dismantled, its external dimensions were measured and compared to the one connected to the speedometer system. Upon establishing that the external dimensions were same, it was resolved to discard the option of casting another journal box cover as it was an expensive option. There were several DE wheel

axles with journal box covers at Mbeya workshop that were reclaimed from accidented locomotives.

The DFH₂ journal box cover details (diameter of holes and distance between them) were used to drill holes on the DE journal box cover. This task was accomplished using a drilling machine.

f. Wheel axle holes

Wheel axles are heat treated and of standard length. The holes are provided in the axle for mounting a circular plate that holds the fork assembly. The wheel axles are very expensive (K 6,000 each) and therefore, it was resolved to maintain the DE wheel axle holes and to adjust the thickness of the circular plate and the length of the bolts holding the circular plate as the thickness of the plate increased.

g. Cow-cature (locomotive bumper)

This is installed to remove obstacles from the railway strip and to generally protect some delicate parts of the locomotive body. When installed on the journal box cover, both DFH₂ and DE transducers protrude outwards beyond the cow-cature making it susceptible to foreign objects found on the railway. Two design options were available at this stage: to extend the existing DE bumper on either side or to fabricate a U-shaped bracket to protect the transducer as illustrated in Figure 3.19. Considering the fabrication skills and material required to extend the length of the DE bumper, it was resolved to fabricate a simple and 12mm thick bracket to be welded on the surface of the DE journal box cover shown in figure 3.15 and 3.19. The arc welding process was used to accomplish this task.

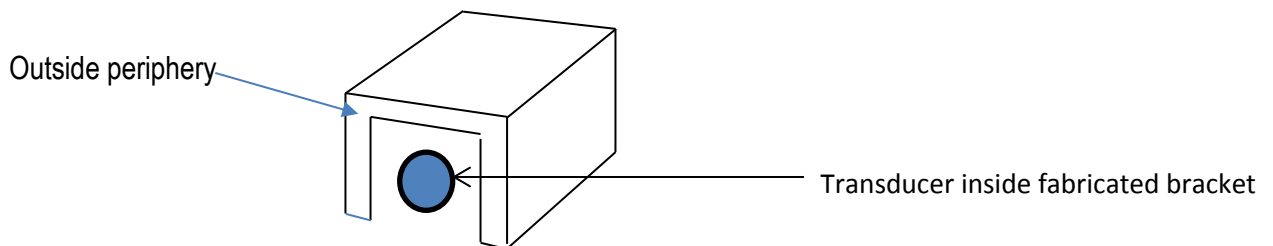


Figure 3.19: U-shaped bracket to protect transducer

3.8 CALIBRATION

As the locomotive moves the tyre tread gets worn over time and eventually the wheel diameter reduces. This reduction in diameter has an impact on the accuracy of speedometer readings and therefore, it is necessary that the speedometer gauge and the transducer are matched according to the wheel diameter (Sections 2.7.6 and 2.8). Using the DE locomotive wheel diameter, the DFH₂ based speedometer gauge and transducer were matched through calibration on the speedometer test stand. During the process of calibration and adjustment, the speed indication of the test speedometer gauge was matched to the standard speed to ensure satisfaction of the relationship depicted in Figure 2.16 and Section 2.9.

The speedometer gauge also has a mileage counter (odometer) that indicates the distance travelled. The accuracy of the mileage counter could not be ascertained in the standard laboratory and therefore, pre-determined distances between railway stations were used to determine the precision of the mileage counter. Important to the accuracy of the mileage counter are wheel diameter and the number of worm gear teeth. The mileage counter performance and the measured wheel diameter gave an indication of the required number of worm gear teeth.

3.9 RAIL-LINE TESTS

After redesigning, adjustment and installation of DFH₂ based speedometer system parts on the DE locomotive, it became imperative to subject the locomotive to rail line tests to ascertain the performance of the DFH₂ based speedometer system. During and after rail line tests particular attention was given to the following:

- i. The sentry panel voltage (V_{sp}) was measured using a Voltmeter at particular locomotive speed (Km/h) and recorded for further comparison with the DE locomotive manufacturer's standards. Table 3.2 depicts a record sheet used for recording the sentry panel voltage during line tests.

Table 3.2: Record Sheet - Voltage and locomotive speed

$V(\text{km/h})$	10	20	30	36	40	50	60
V_{SP}	-	-	-	-	-	-	-

According to the repair and maintenance manuals for DFH₂ (1976) and DE (1979) speedometer systems, the travel speed (V) of the locomotive is given by:

$$n = \frac{10V}{60\pi D} \quad (3.1)$$

Where: n = Axle rotating speed in rpm,

V = travel speed in km/h,

D = wheel diameter in mm.

- ii. The mileage counter readings at particular railway station intervals were recorded and compared to the actual distances. During the first two line tests the mileage counter readings did not correspond to the actual distance covered. After changing the worm gear, the mileage counter readings corresponded to the actual distance between railway stations. Table 3.3 was prepared with predetermined distances between stations and whenever a locomotive reached a particular station, the mileage counter (odometer) readings were recorded against a predetermined distance for the purpose of making comparisons between the two.

Table 3.3: Record Sheet of actual distance between stations and mileage counter readings

Stations	Actual Distance (Km)	Mileage Counter Reading (Km)
<i>Mbeya – Mbalizi</i>	5	-
<i>Mbalizi – Vwawa</i>	20	-
<i>Tunduma – Nakonde</i>	2	-
<i>Nakonde – Mwanzo</i>	15	-

- iii. The movement of the speedometer gauge pointer was monitored consistently for uniformity and smoothness as the locomotive accelerated. During the first line test the pointer rose as the locomotive accelerated but eventually dropped rapidly beyond the zero mark of the speedometer gauge. After the first line test, the speedometer was opened and status of its spiral spring checked for deformation;
- iv. After line test, the transducer and the journal box cover were removed to check the resultant state of the circular plate, square shank and the drive shaft. Initially a thin circular plate was used and after noticing some deformation, its thickness was gradually increased. Later its shape changed to a triangle as indicated in Figure 3.20 until satisfactory results were obtained;

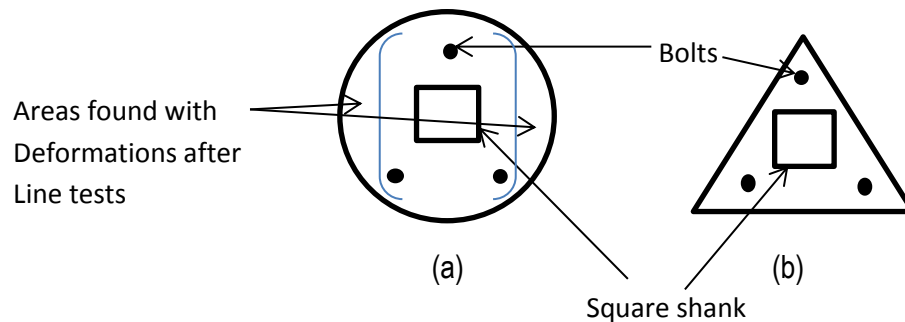


Figure 3.20: Circular and triangular plates

- v. After establishing that the DFH₂ based speedometer system had responded positively on the DE locomotive, a U-shaped bracket was fabricated using a 12 mm thick plate and welded on the DE journal box cover to protect the transducer from foreign obstacles on the railway.

3.10 SYSTEM REFINEMENT AND DOCUMENTATION

After line tests, it was found that both the square shank peripheral and circular plate had deformed. This deformation was attributed to its smaller thickness and shape. Therefore, the thickness was gradually increased and shape changed to triangular until an optimal thickness giving uniformity in the pointer movement and accurate speedometer readings was attained.

Maximum plate thickness allowable.

Using a meter rule and depth gauge to determine the length of the axle bolts and the depth of the bolt holes in the wheel axle, the following measurements were obtained:

- a) Length of the axle bolts = 12 mm
- b) Depth of bolt holes in wheel axle = 13 mm

In order to get satisfactory results and required firmness in the assembly of the circular plate to the wheel axle, the bolt needed enter at least 5 mm into the wheel axle. Therefore, the difference between the length of the axle bolts and the acceptable minimum penetration depth of the bolt into the axle hole ($12 - 5 = 7$ mm) translated into maximum plate thickness allowable.

During locomotive line tests it was discovered that despite several attempts to calibrate the mileage counter, the output readings were different from the actual distances between particular stations. The calibration and adjustments was done in accordance with the DE locomotive wheel diameter but still the mileage indications were different from the actual distance between reference stations.

After using the principle governing the choice of worm gear teeth number (2.7.5), another worm gear with 36 teeth was drawn from stores to replace the initial one with 34 teeth and the mileage counter readings tallied with the actual distances between particular stations.

The outside periphery of the u-shaped bracket shown in Figure 3.19 was made to be aligned with the outermost part of the locomotive bumper in Figure 1.1 and had enough internal space for the screw driver to enter and unscrew the transducer bolts from the journal box cover. This was important for the purpose of servicing and repairing the transducer.

After obtaining the required line test results of the mileage counter and speedometer readings, it became necessary to make refinements to the redesigned DFH₂ based speedometer system. After certifying the performance of the redesigned system, all component specifications pertaining to the final system were recorded and properly documented in the central laboratory as given by engineering drawings in section 3.4 and workshop library for future reference and use.

CHAPTER 4

REDESIGN AND MANUFACTURE OF THE SYSTEM

4.1 INTRODUCTION

This chapter provides a narration on constituted redesigning and manufacture of the DFH₂ based speedometer system components. This chapter, further highlights and stipulates the final adopted system components and their respective dimensions.

4.2 REDESIGNING SYSTEM COMPONENTS

The process of redesigning involved the analysis of the speedometer system parts in relation to their particular functions and the assessment of alternative and most economical means of achieving the same functions to ensure systems compatibility (DFH₂ and DE systems). From this perspective, some system components were totally substituted by others that could be economically made in house (TAZARA) with locally available materials and production facilities to ensure system sustainability.

Further, based on proven scientific principles (concepts) highlighted in chapter 2, redesigning involved changing specifications of some DFH₂ system components to make them compatible with specifications of similar DE components.

In order to prevent the replication of deficiencies associated with the original DE and DFH₂ speedometer systems, new components were introduced onto the redesigned DFH₂ based speedometer system.

4.2.1 REDESIGNED SYSTEM COMPONENTS AND SPECIFICATIONS

The following critical DFH₂ speedometer component parts were analysed and assessed with a view to substituting them or changing their specifications to ensure system compatibility with the DE system:

a) Fork Assembly and Circular Plate

In both systems, the fork assembly is installed for the purpose of transmitting the rotary motion of the locomotive wheel axle and current to the transducer via the drive shaft. The DE fork assembly was larger and therefore, could not be used to hold the DFH₂ drive shaft. The assembly requirement for the DFH₂ fork assembly to the DFH₂ wheel axle was different from that of the DE system.

Taking advantage of the longer length of the DFH₂ square drive shaft (table 3.1), presence of the circular plate in the DE system and based on the derived minimum plate thickness allowable (Section 3.7), a 6 mm thick triangular plate incorporating an 18.2 mm square shank was made (Figure 3.20) and installed to replace the original DE 3 mm thick circular plate. The triangular plate was made to serve the purpose of transmitting the axle rotary motion and current onto the transducer drive shaft. The triangular plate with 60 mm equal sides replaced the DE fork assembly and hence the final redesigned system did not have a fork assembly as shown in figures 3.15, 3.16 and 3.17.

b) Worm gear and wheel diameter

According to Section 2.7.5 choosing of worm gear teeth number depended on the wheel diameter. The number of the worm gear teeth for the large wheel diameter was less than those for a small wheel diameter. Further, the accuracy of the mileage counter equally depended on the relationship between the number worm gear teeth and the locomotive wheel diameter. The DFH₂ mileage counter had a worm gear with 36 teeth. The mileage counter is incorporated in the speedometer gauge. The DE locomotive wheel diameter is 900 mm and the DFH₂ wheel diameter is 915 mm. Based on the above concept, a worm

gear with 34mm teeth was drawn from stores to replace the original DFH₂ worm gear with 36 teeth. Failure to apply this concept, accurate travel distances can never be attained regardless of the number of attempts made to calibrate and adjust the system.

The other option would have been to use a DFH₂ wheel set on a DE locomotive but, however, looking at the complications (cost and assembly requirements) involved supplemented by the variation in the wheel size between the DFH₂ and DE wheels, a resolve was made to use another worm gear. This was much more economical as using a DFH₂ wheelset would have translated into about 48 man hrs at K10 per hour for a Technician translating into K480 for boring of a mono block and press fitting of an axle into the mono block.

c) Journal box cover and Transducer

The DFH₂ transducer is mounted on the journal box cover by means of four bolts and nuts. The DE transducer is mounted similarly, however, it is smaller than the DFH₂ transducer (Table 3.1). This implies that it would practically be not easy to mount the DFH₂ transducer onto the DE journal box cover as an attempt to enlarge the original DE journal box cover bolt holes would weaken or damage the cover.

To avoid compromise in the firmity of the transmission axis, a resolve was made to make use of a DE journal box cover meant for wheel sets other than that connected to the speedometer system. This cover has the same dimensions as that connected to the DE speedometer system except that it has no holes for mounting the transducer. Four holes suitable for mounting the DFH₂ transducer were drilled in the DE journal box cover. This was the most economical option of resolving the challenge as the DE journal box covers were in abundance and consequently prevented the cost associated with buying new or casting other covers.

d) Transducer Bracket

The transducers are mounted on the journal box cover for both DE and DFH₂ locomotives. In the original designs the transducers were not shielded and therefore, susceptible to various obstacles on the rail track. This deficiency resulted in the damage or loss of transducers whenever they came into contact with such obstacles. To permanently arrest this costly omission, the need to fabricate a suitable bracket to shield the transducer was critically assessed and considered.

Taking advantage of the space between the transducer peripherals and the journal box cover bolts, measurements were taken to facilitate the fabrication of an appropriate and firm bracket to shield the transducer. The space was ample enough to make use of a 12 mm sheet metal for the bracket. The external dimensions of the transducer and cow-cature provided guidance on the determination of the transducer dimensions. The following were used to aid the fabrication of a bracket:

- i. The length of the DFH₂ transducer is 245 mm. Therefore, the appropriate length of the bracket was found to be 250 mm. This was found to be suitable as the length of the bracket did not exceed the outer surface of the locomotive bumper or cow-cature;
- ii. The total transducer width is 200 mm. Therefore, it was found inevitable to add 2.5mm on either side of the transducer width. This translated into a total of 205 mm bracket width; and
- iii. The total height of the transducer was less than 45 mm. The height of the bracket was therefore put at 50 mm. Table 3.4 shows the dimensions of DE speedometer components.

Table 3.4 DE Speedometer component Dimensions

Component Name	Length (mm)	Height (mm)	Width (mm)	Diameter (mm)
<i>U-Shaped</i>	250	50	205	N/A

<i>Bracket</i>				
<i>DE Mono block</i>	-	-	-	900
<i>(Wheel Set)</i>				

The other consideration made was on the appropriate method to be used for mounting the U-shaped bracket on the journal box cover. The focus was on the type of the material used for the journal box cover. The journal box cover was a cast steel and therefore, a resolve was made to weld the U-shaped bracket onto the journal box cover.

4.3 REDESIGN OR BUY DECISION OPTIONS

After completion of the redesigning process, installation and line tests, it was necessary to make a comparison of two decision options involving whether to redesign or buy the required speedometer system. Table 3.5 below provides a standard costing method used to ascertain the total cost of the redesigned speedometer system per locomotive and associated savings.

Table 3.5 Redesign or Buy Cost Analysis

No.	Description	Unit	Quantity	Unit Cost (ZMK)	Total Cost (ZMK)
A. Material Requirements:					
	Petrol	litre	1	12	12
	Mutton cloth	roll	1	50	50
	Sheet metal for bracket/plate	each		scrap available	0
	Welding Rods for bracket	each			50
	Voltmeter	each	1	100	100
	Cables (available on DE)	roll		Original available	0
	Diesel for line test	litre	50	11	550
B.	Welding Machine	hr	2	3	6
C. Labour:					
	Calibration & Adjustment	hr	3	10.42/h*2	62.52

Drilling of holes on journal Cover	hr	1	10.42/h	10.42
Installation on locomotive	hr	2	10.42/hr*2	41.68
Line Test (60km)	hr	6	10.42/hr*2	125.04

D. Prime Cost (A+B+C) **1,007.62**

E. Fixed Costs @ 30% **303.00**

F. Total Cost (Redesign) = K 1, 310.62/Locomotive

G. Total Cost (Buying new DE System) = K 45, 600/Locomotive

Therefore, saving as a result of Redesigning = G – F

= **K 44, 280/Locomotive**

CHAPTER 5

LINE TESTS RESULTS AND DISCUSSIONS

5.1 INTRODUCTION

This chapter presents results obtained during laboratory calibration and adjustment of the system components, rail line tests of locomotive number DE 1027 to ascertain the performance and conformance of the redesigned DFH₂ speedometer system to the DE locomotive standards. Focus was on the stability of the transmission axis to attain the DE standards, avoid vibrations and accuracy in the mileage counter readings through the application of concepts and principles presented in Chapter 2.

5.2 SPEEDOMETER SYSTEM CALIBRATION AND ADJUSTMENT TEST RESULTS.

5.2.1 Calibration and Adjustment to match the DFH₂ Speedometer gauge with a DFH₂ based transducer at wheel diameter of 915mm.

The essence of matching the original DFH₂ components was to assess whether or not they were in good working order prior to using them on a DE locomotive. Table 4.1 provides laboratory calibration test results.

Table 5.1: Calibration results of DFH₂ Components

TEST STAND RESULTS		DFH ₂ SYSTEM TEST RESULTS	
Speedometer Km/h	Mileage Counter Km	Speedometer Km/h	Mileage Counter Km
0	0	0	0
10		15	
20	20	26	20
30		38	
40		45	
50	50	48	50
60		53	
70		45	
80	80	30	80
90		22	
100		0	
120	150	0	150

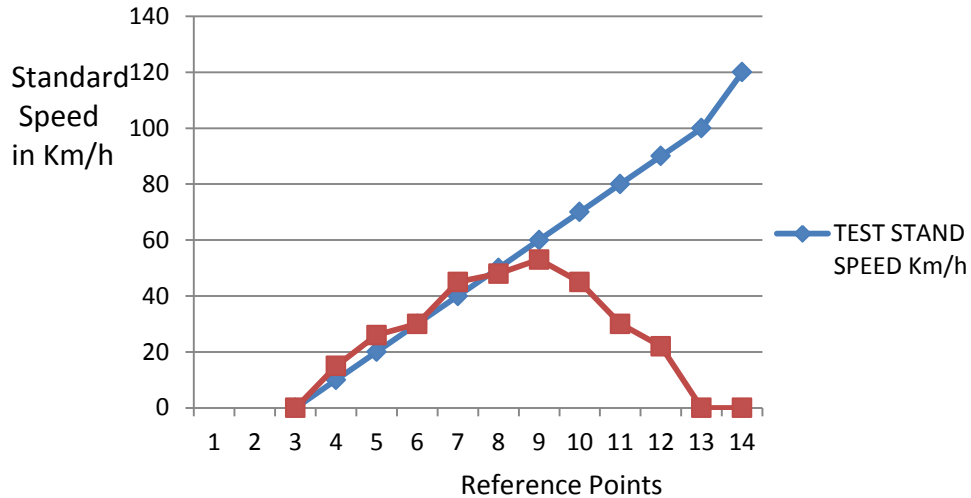


Figure 5.1: Trends in calibration results

During laboratory calibration and adjustment process, the wheel diameter on the test stand was set at 915 mm corresponding to the DFH₂ wheel diameter. The Table 4.1 indicates that initially the DFH₂ speedometer pointer rose to a speed of 53 Km/h and suddenly, started declining rapidly whilst hydraulic pressure of the test stand was increased. The table also shows that the DFH₂ speedometer gauge test results were above the DFH₂ speedometer minimum acceptable deviation of 1.5 Km/h. Despite adjusting the speedometer pointer several times, it exhibited the same behaviour pattern. Using the concept described in Section 2.7.8, the spiral spring in the speedometer gauge was replaced and the speedometer gauge was subjected to another calibration and adjustment. Table 4.1 further indicates that the Mileage Counter test results matched the laboratory Test stand results.

5.2.2 Matching the DFH₂ Speedometer gauge with the DFH₂ Transducer after replacement of spiral spring (at wheel diameter of 915mm)

The behaviour pattern in the movement of the speedometer pointer prompted the opening of the gauge to check the condition of the spiral spring. The spiral spring was deformed and therefore, was replaced by a new one. Table 4.3 provides calibration and adjustment results after the replacement of the spiral spring.

Table 5.2: Calibration and Adjustment results after spiral spring replacement

TEST STAND RESULTS		DFH₂ SYSTEM TEST RESULTS	
Speedometer Km/h	Mileage Counter Km	Speedometer Km/h	Mileage Counter Km
0	0	0	0
10		12	
20	20	22	20
30		32	
40		42	
50	50	52	50
60		60	
70		70	
80	80	80	80
90		90	
100		100	
120	150	120	150

The DFH₂ speedometer pointer rose uniformly as the pressure increased. Despite uniformity in the rising of the pointer, the results indicated that the test gauge was above the test stand by a constant speed of 2 Km/h. After adjusting the pointer at a speed of 60 Km/h, the results of the gauge matched the test stand meeting the concept narrated under Section 2.8.1 as indicated in Table 4.4. Further, the results in Table 4.4 indicate that the speedometer mileage counter readings matched the test stand readings. Table 4.4 provides the overall calibration and adjustment results after the adjustment of the speedometer pointer.

Table 5.3: Speed comparisons after pointer adjustment

TEST STAND RESULTS		DFH ₂ SYSTEM TEST RESULTS	
Speedometer Km/h	Mileage Counter Km	Speedometer Km/h	Mileage Counter Km
0	0	0	0
10		10	
20	20	20	20
30		30	
40		40	
50	50	50	50
60		60	
70		70	
80	80	80	80
90		90	
100		100	
120	150	120	150

5.2.3 Matching the DFH₂ Speedometer gauge and Transducer at wheel diameter of 900mm (corresponding to the DE wheel diameter).

After matching the DFH₂ transducer with the DFH₂ speedometer gauge it was ascertained that the two components were in good working order and could be utilised on the DE locomotive. However, the DFH₂ and DE wheel diameters were different and therefore, it became necessary to suit the DFH₂ transducer and speedometer gauge according to the DE wheel diameter of 900 mm. Table 4.5 shows the calibration and adjustment results using the DE wheel diameter of 900mm.

Table 5.4 Calibration results at wheel diameter of 900mm

TEST STAND RESULTS		DFH ₂ SYSTEM TEST RESULTS	
Speedometer Km/h	Mileage Counter Km	Speedometer Km/h	Mileage Counter Km
0	0	0	0
10		10	
20	20	20	23.61
30		30	
40		40	
50	50	50	
60		60	
70		70	
80	80	80	75.56
90		90	
100		100	
120	150	120	141

The results indicate that the speedometer test gauge readings matched the readings of the test stand. However, the readings of the mileage counter (odometer) were different from the readings of the test stand despite several attempts to make adjustments.

5.3 LINE TEST RESULTS.

Table 4.6 provides line test results of the DFH₂ speedometer system configured at DE locomotive wheel diameter of 900 mm. Despite the failure to match the DFH₂ mileage counter with the test stand through laboratory adjustments, the DFH₂ speedometer gauge and transducer were assembled on the DE locomotive. The DFH₂ transducer was connected to the DE locomotive wheel axle via circular plates of thickness ranging from 3 mm to 7 mm in order to further assess the performance of the speedometer system and mileage counter.

Table 5.5 Line test results of DFH₂ System at DE wheel diameter = 900mm

Distance (Km) between stations	DE Locomotive Speedometer (km/h)	Sentry Panel Voltage (volts)	Mileage Counter (Km)
25	10	0.83	23.61
	19.8	1.66	
	25	2.50	
80	20	3.00	75.56
	17	3.33	
	0	4.16	
100	0	5.00	141

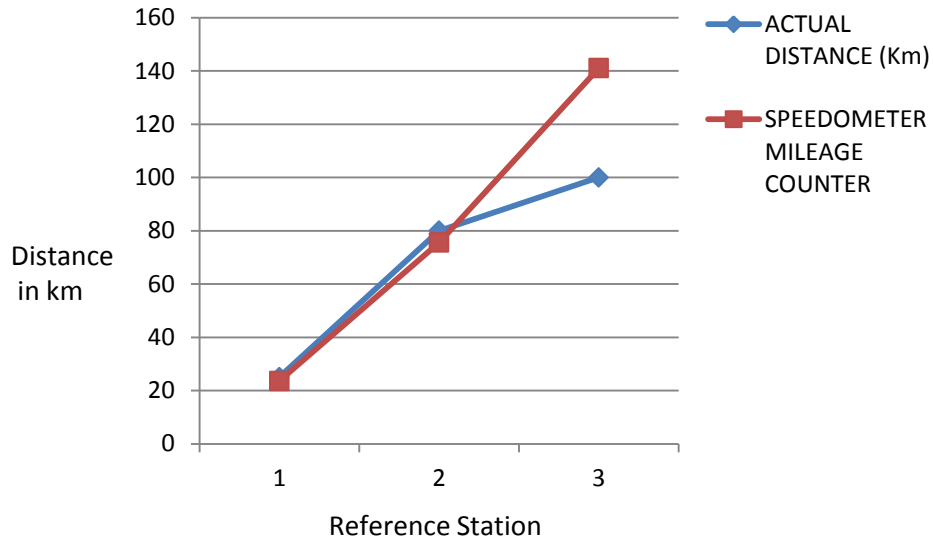


Figure 5.2: Actual distance Vs Mileage Counter reading

Table 5.1 indicates that as the locomotive accelerated, the sentry panel voltage recorded from the voltmeter increased. However, the speedometer pointer rose to a maximum speed of 25 Km/h and suddenly retracted to zero whilst the actual speed of the locomotive increased. The speedometer pointer movement pattern was similar at circular plate thickness between 3 mm and 5 mm. This was contrary to the DE standard relationship described in Section 2.9.

After the first few line tests, the transducer and journal box cover were dismantled from the DE wheel axle and it was found that circular plates of thickness from 3 mm to 5 mm were deformed. Basing on the concept in Section 2.7.7, the plate thickness was gradually increased to determine the most optimal thickness and required transmission axis stability. At 5 mm circular plate thickness, the speedometer pointer rose uniformly and extent of deformation on the plate was minimal. At 6 mm thickness no deformation was observed. When an attempt was made to further increase the thickness to 7 mm, it became difficult to assemble the DFH₂ transducer to the DE wheel axle. As the thickness of the plate increased, stability of the transmission axis and uniformity in the speedometer pointer movement also improved. This was attributed to the fact that as the plate thickness increased, a large portion of the transducer drive shaft entered into the circular plate thereby stabilising the transmission axis and avoiding vibration.

5.3.1 LINE TEST OF CONFIGURED SPEEDOMETER AND TRANSDUCER BASED ON THE CIRCULAR PLATE OF 6mm THICKNESS

Although the readings of the speedometer and sentry panel voltage matched DE standards, the mileage counter readings did not match the actual distances between reference stations as indicated in Figure 5.6. Further, some minor deformations were also observed near the peripherals of the circular plate.

Table 5.6: Line test results after increasing circular plate thickness to 6mm

ACTUAL DISTANCE Km	SPEED GAUGE Km/h	SENTRY PANEL VOLTAGE (V_{sp})	SPEED GAUGE MILEAGE COUNTER Km
25	10	0.83	23.61
	20	1.66	
	30	2.50	
80	36	3.00	75.56
	40	3.33	
	50	4.16	

100	60	5.00	141
-----	----	------	-----

5.3.2 LINE TEST OF CONFIGURED SPEEDOMETER AND TRANSDUCER BASED ON THE SECOND DESIGN (TRIANGULAR PLATE DESIGN) WITH PLATE THICKNESS = 6mm

In a bid to overcome the deformations on the peripherals of the circular plate, a triangular plate with thick ness of 6mm was utilised instead of a circular plate. After installation of the triangular plate another subsequent line test was conducted and yielded results shown in Table 5.7

Table 5.7: Line test results using a triangular plate of 6mm thickness.

ACTUAL DISTANCE Km	SPEED GAUGE Km/h	SENTRY PANEL VOLTAGE (V_{sp})	SPEED GAUGE MILEAGE COUNTER Km
25	10	0.83	23.61
	20	1.66	
	30	2.50	
80	36	3.00	75.56
	40	3.33	

	50	4.16	
150	60	5.00	141

Although the mileage counter readings did not match the actual distance between stations, the problem of deformations on the peripherals was no longer encountered after using a triangular plate of 6mm thickness.

At specific sentry panel voltage as shown in Table 4.8, speedometer readings were recorded to facilitate comparison with DE standards described in Section 2.9. The speedometer gauge and sentry panel readings conformed to the DE locomotives standards as reflected in Figure 5.3.

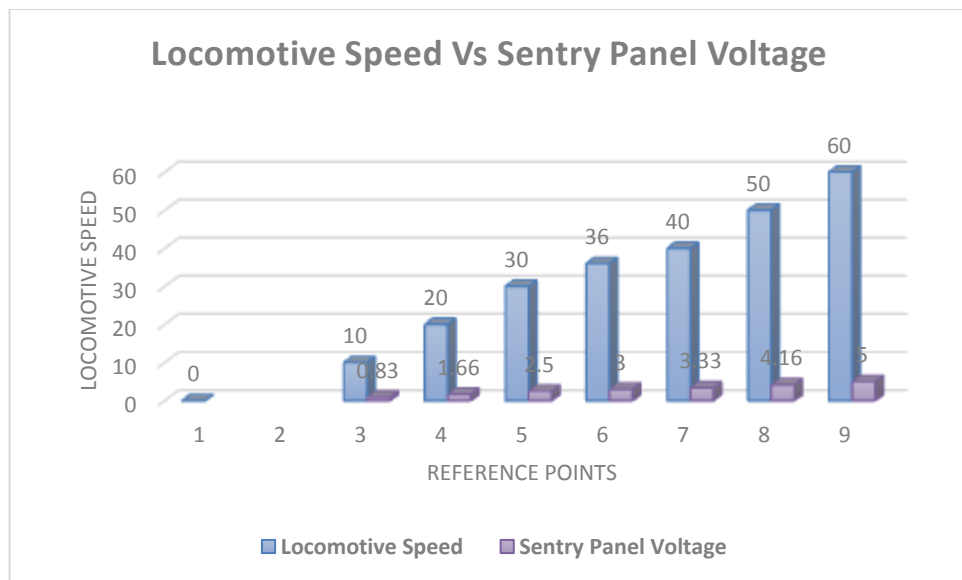


Figure 5.3: Relationship between locomotive speed and sentry panel voltage.

5.4 ACTUAL DISTANCE VS SPEEDOMETER MILEAGE COUNTER

During calibration and adjustments at wheel diameter of 900 mm, the mileage counter readings did not match the readings of the test stand. Furthermore, during locomotive line tests, the

mileage counter readings were also different from the actual distance travelled between reference stations. Table 4.9 provides results of actual distance and mileage counter recorded after changing the worm gears.

Table 5.8: Line test results of Actual Distance covered and Mileage Counter readings

ACTUAL DISTANCE (Km)	SPEED GAUGE (Km/h)	SENTRY PANEL VOLTAGE (V_{sp}) (V)	SPEED GAUGE MILEAGE COUNTER (Km)
25	10	0.83	25
	20	1.66	
	30	2.50	
80	36	3.00	80
	40	3.33	
	50	4.16	
150	60	5.00	150

Using the concept set in Section 2.7.5, the mileage counter worm gear with 34 teeth was replaced by another with 36 teeth and after some line tests, the mileage counter readings matched with the predetermined distances between reference stations as depicted in Table 5.9.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 INTRODUCTION

This final chapter consists of four sections. Based on test results, the first section summarises the conclusions and findings of the research presented in this dissertation. The second section gives limitations and recommendations.

6.2 CONCLUSIONS

The realisation of table 5.3 and final design engineering drawings given by figures 3.15, 3.16 and 3.17 depicts success recorded in the configuration of the DFH₂ speedometer system components and in the redesigning process to ensure compatibility to DE locomotives. This absolutely suggests achievement of research specific objectives (i) and (ii). This was necessitated by the successful application of principles and concepts prescribed in chapters 2.

Tables 5.1, 5.5, 5.6 and 5.9 indicate that the number of worm gear teeth and wheel diameter have an important bearing on the accuracy of the mileage counter (odometer) output. Table 5.9 further culminates in the absolute achievement of research objective number (i).

Figure 3.15 of the final engineering drawings incorporates a U-shaped bracket welded on the journal box cover of the wheel set provides a lasting solution to the problem of losing transducers whenever they hit foreign obstacles on the rail line. Further, the introduction of a bracket also provided for the mounting requirements of the transducer to the wheel axle as stipulated under Section 2.7.1. The introduction of a U-shaped bracket to protect the transducer suggests achievement of research specific objective number (iii).

The practical attainment of table 5.9 through line tests reflects conformance of the final DFH₂ speedometer system to the DE standards thereby achieving research objective number (iv) and (v).

Section 4.3 indicate that length of the driving shaft (L) and thickness of the plate (incorporating square shank) have an effect on stability of the transmission axis and over performance of the speedometer system. In this case, the amount by which the drive shaft enters the plate square shank is very important if the conditions of parallelism and concentricity stipulated under Section 2.5.3 are to be fulfilled.

The condition of the spiral spring has an effect on the nature of the speedometer pointer movement as revealed in Tables 5.1 and 5.3.

6.3 FINDINGS AND STUDY OUTCOMES

The key finding included the fact that one transducer can be used for two speedometer gauges installed at different locomotive ends provided they are calibrated and adjusted at the same locomotive wheel diameter. The major outcome of the study is that the final DFH₂ based speedometer system depicted by figure 3.15 was successfully installed on DE locomotive number 1027 and TAZARA has since continued with the installation of new system on all DE locomotives operating without speedometers.

6.4 LIMITATIONS AND RECOMMENDATIONS

6.4.1 LIMITATIONS

The major limitation is that no studies in the area of speedometer system redesigning could be accessed and reviewed to facilitate practical comparisons with the literature available on the DE and DFH₂ speedometer systems. Therefore, the provided solution was derived through the application of concepts and principles given in chapter 2.

It was difficult to accelerate installation of the redesigned DFH₂ speedometer system on all the DE locomotives that did not have a speedometer system as TAZARA had very few DE locomotives which were usually busy in railway operations.

6.4.2 RECOMMENDATIONS

DFH₂ based speedometer system components were installed on a DE locomotive number 1027. Despite installing on a different locomotive model, maintenance/service requirements should be based on the DFH₂ repair and service manual. Appendix H and I provide guidance on how to trouble shooting and maintenance of various speedometer gauge and mileage counter system components.

All DE locomotives without speedometer system should be installed with DFH₂ speedometer system to avoid the problem of over speeding and avoidable accidents. This will also contribute to punctuality of trains, recapturing of lost customers and increased profitability of TAZARA.

To preserve the scarce transducers, one transducer should be calibrated, adjusted and used for two speedometer gauges. This will imply that one transducer will carter for two locomotive ends and reduce on the cost.

The diameter of the wheel (mono block) connected to the speedometer system should be checked at stipulated intervals to avoid inaccuracies of the speedometer system due to wear on the tyre tread.

TAZARA has a lot of scrap, locomotive, coach and wagon spares in various stores. One of the major factors contributing to under performance of the authority is deferred maintenance of the equipment due to lack of spares. TAZARA should establish a department of “Research and Development” to focus on redesigning and manufacture of such important spares.

REFERENCES

1. Kazuo A., 2003. Low-noise drive technology of brushless motor. RENGA No. 163, pp19-25, 2003.
2. Rhodes A., 2000. Repairing Jaeger and Smiths Speedometers Manual. England: Moss Motors Co., Ltd
3. Agy D., 1994. Calibration Philosophy in Practice, 2nd Edition. Fluke Corporation, Everett, WA.
4. William E., 1973. A history of Marine Navigation, G.T. Foulis 7 Co. Ltd., Henley-on-Thames, Oxfordshire.
5. Liptak, Bela G., 2003. Instrument Engineers' Handbook. Process Measurement and Analysis Volume 1, 4th Edition: New York, CRC Press.
6. Kidanemariam G., 2014. Predicting the Analysis of Fretting Damage for Addis Ababa Light Rail Train Wheel Set, MSc Dissertation. Ethiopia: Addis Ababa University.
7. Mir-Nasiri, N., 2015. Sensors and Actuators. Nazarbayev University, School of Engineering.

8. Kure G., Martinetti M., 2005. New Sensor Solutions for Railways. SKF Solutions Magazine.
9. Krupp A., 1980. Sentry Panel Voltage and Speed. Krupp Locomotives Hand Book 1, pp 2-5, 1980.
10. Waldemar G., 2002. Tachogenerator. Brazil: WEG Jaraguado Sul.
11. Dong F. H., 1974. Speedometer System Manual – Repair and Maintenance: China Shanghai Telecommunications Co., Ltd.
12. Joseph W. J., 1904. Speedometer: A simple Mechanical Speedometer from the Early 20th Century, New York.
13. Koji N., Masayoshi S., 1999. New Control Method of three-phase indication motor. RENGA No. 159, pp 23 – 28.
14. Taylor M., Lynam D., Baruya A., 2000. The Effects of drivers' speed on the frequency of road accidents. Transport Research Laboratory TRL., Report 42., Crowthome.
15. Green P., 1983. What do drivers say they use Speedometers and tachometers for? University of Michigan Transportation Institute.
16. Knippling, R., 2000. Changing driver behaviour with on-board safety monitoring. Volume VIII, No. 2, pp. 27 – 35.
17. John K. S., 1912. Magnetic Speedometer: A typical Eddy – Current Speedometer. United States: University of Chicago.
18. Lang H., 2001. Vibration to Electric Energy Conversion: Large Scale Transactions Systems, Volume 9
19. Warner S., 2001. How a tachometer/speedometer works using magnetic sensor. Manual for control instruments. Volume 2, pp. 35 – 38.
20. Denton T., 2004. Automobile Electrical and Electronic System, 3rd Edition. Hodder Headline plc, Great Britain.
21. Qing-Ming W., 2012. Principles of Electromechanical Sensors and Actuators. London: University of Pittsburgh.
22. AC Motor Technology Study Group, 1998. Book to Understand AC small motor. Kagyo
23. Chosati Publishing.
24. Stewart Warner Co., 2001. How a tachometer/Speedometer Works Using Magnetic Sensor Manual.

25. Norton H. N., 2015. Handbook of Transducers.
26. Diesel Electric Manual, 1980. Sentry Panel Voltage and locomotive speed. Krupp, Germany.
27. Karim N., 2001. *How odometers work hand book*, viewed July, 2015, <<http://www.howstuffworks.com>>
28. Alan M., 2005., *How Speedometer is made* (Manufacture and history), volume 7, viewed July, 2016, <[html:www.madehow.com](http://www.madehow.com)>
29. Speedometer Repair Guy, 2005. *Secrets of Speedometer Repair*, viewed May 2015, <<http://www.speedometer-odometer-repair.com/artical6.html>>
30. SKF Group, 2010. Railway Technical Handbook. Drive Systems: Traction Motor and Gear Box Bearings, Sensors, Condition Monitoring and Services, Volume 2.
31. Jeffrey J. K., 2007. *The Development of Automobile Speedometer Dials*, viewed September, 2016, <[http://epublications, bond.edu.au/hss_pubs/](http://epublications.bond.edu.au/hss_pubs/) >
32. Chris W. 2016., *How speedometer works*, viewed 15th August, 2018, <[http://www.explainthat stuff.com/](http://www.explainthatstuff.com/)>
33. International Studies Association, 2008. *The Intelligent Speed Adaptation*, viewed May, 2018, <http://www.its.leeds.ac.uk/prjects/ISA/Index.htm>
34. How to Suit, 2017. *How to replace, update, fix and create*, viewed September, 2017, http://www.electronics_tutorials.ws/io/io_1.html.
35. TAZARA, 2015. *The origin and operations of TAZARA*, viewed 25th February, 2017, <https://en.wikipedia.org/wiki/TAZARA_Railway.>

APPENDIX A

A table for wheel diameter-----Axle rotating speed-----Travel Speed.

$$n = \frac{10V}{60\pi D}$$

Where: n = Axle rotating speed in rpm,

V = travel speed in km/h,

D = wheel diameter in mm.

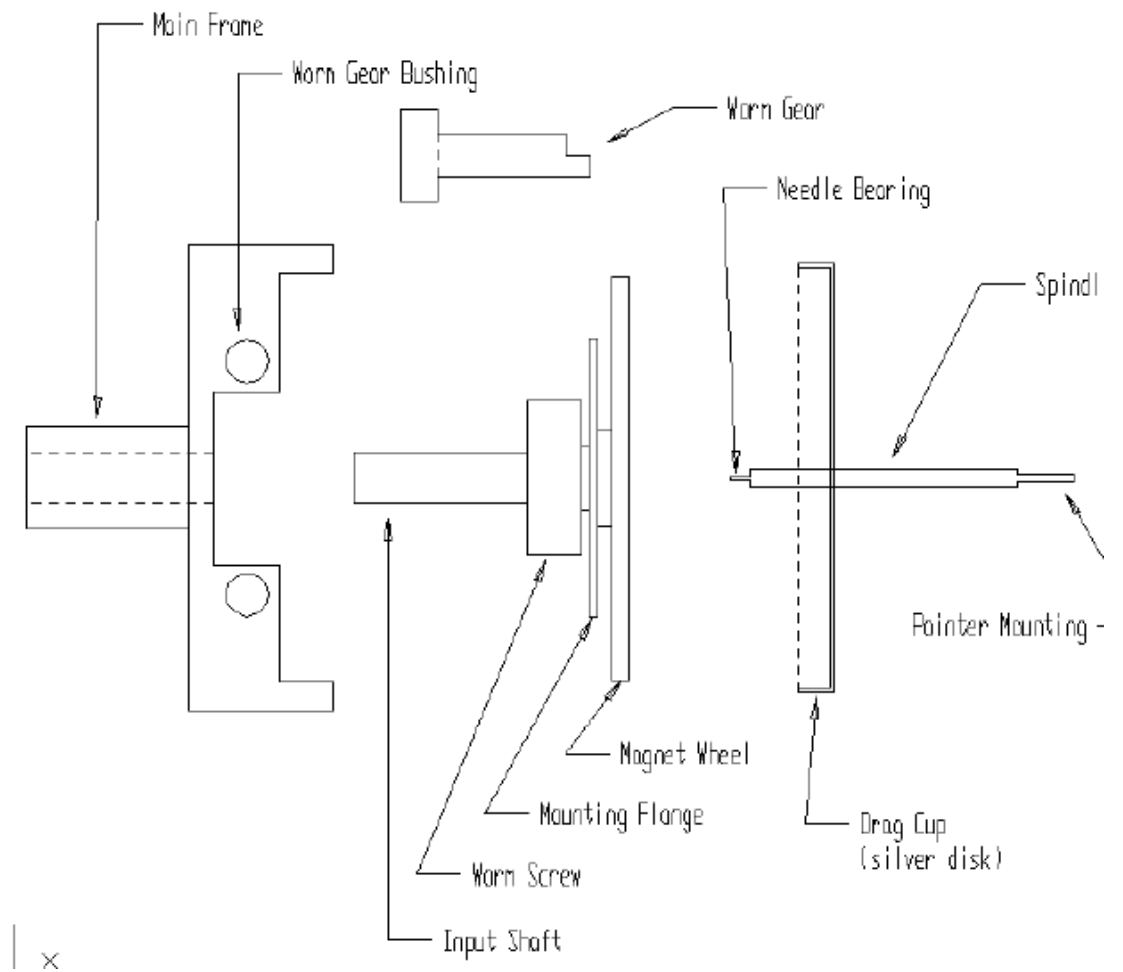
Travel/Rotating speed	Subway Car	DFH* Locomotive	Diesel Locomotive	Electric Locomotive
	Wheel diameter (Ø)			
	840	915	1050	1250

10	63	58	50	42
20	126	116	101	85
30	190	174	151	127
40	253	232	202	170
50	316	316	252	212
60	379	379	302	254
70	443	443	353	297
80	506	506	403	340
90	569	569	454	382
100	632	632	504	424
110	695	695	555	467
120	759	759	605	509
130	822	822	656	552
140	885	885	706	594
150	948	948	757	637
Worm Gear teeth	39	35	31	29

*Narrow gauge.

APPENDIX B

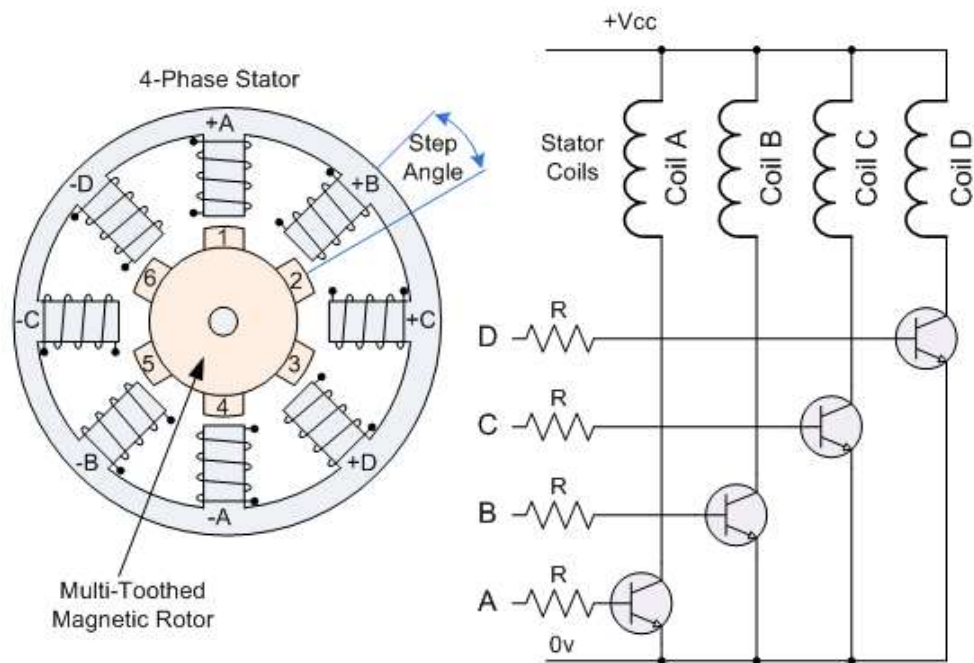
EXPLODED DIAGRAM OF A TYPICAL SPEEDOMETER



APPENDIX C

MOTION SENSORS/ TRANSDUCERS

These include Switches solenoids, relays, motors etc. Motors are divided into direct current such as brushed or brushless, servo and stepper motors. Others are alternating current. Below is a diagram of a stepper motor.



Brushed motor – Permanent magnets on armature, rotor acts as electromagnet while the
brushless motor – Permanent magnet on the rotor, electromagnet on armature are switched.

APPENDIX D

ODOMETER:

A. Mechanical Description

The odometer is gear driven. The cable turns a worm screw which turns a 32 (sometimes 20 or 25) tooth gear. The gear is directly attached to a pawl via an eccentric pivot. Every turn of the gear will pull the pawl once. The pawl turns a gear at the end of the odometer wheels. The gear has a different number of teeth depending on the calibration of the odometer. This Calibration is written in small letters on the dial face above the "MPH". 1152 and 1184 are the most common on the TR4 series; other speedometers may use a 20 or 25 tooth gear and more teeth on the odometer wheel gear. Fewer teeth on the worm gear makes the movement of the odometer wheels much smoother. The calibration is always a whole multiple of the 32 (20 or 25) tooth gear. For instance, 1152 is 32×36 .

There are few places where problems can occur:

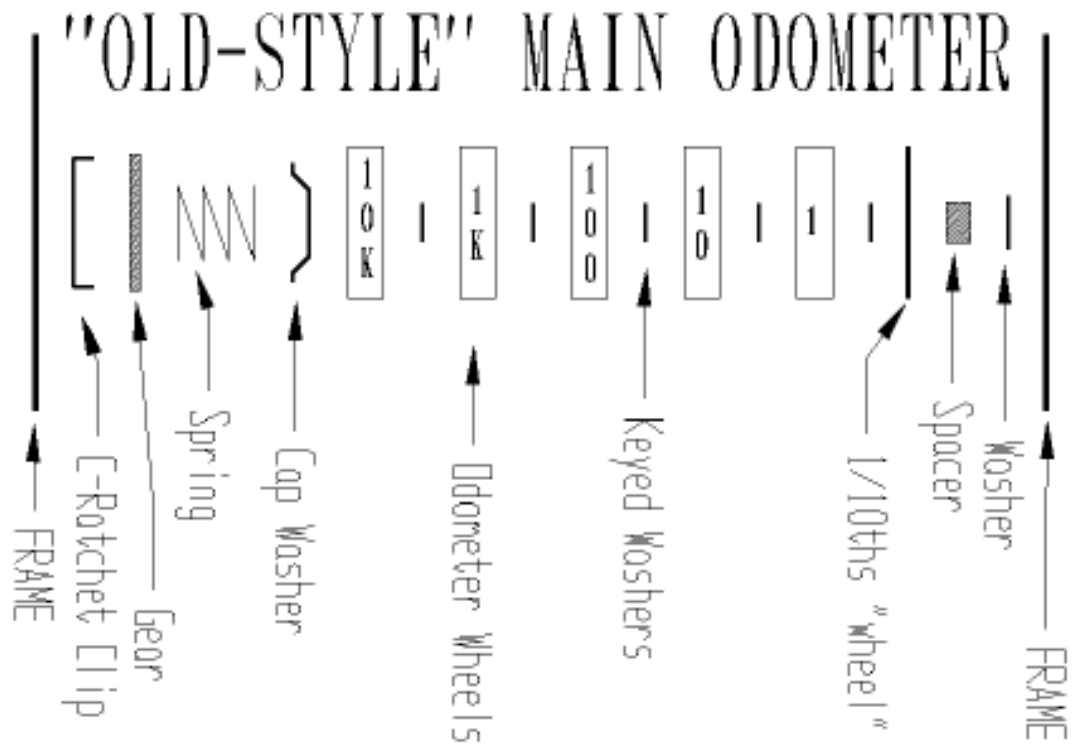
- The worm may not turn;
- The plastic 32 tooth gear can be stripped, or the clip that holds the pawl to the eccentric pivot may have fallen off allowing the pawl to fall from the eccentric.
- The spring pulling the pawl to the gear on the wheels may be weak or missing. This may prevent the pawl from touching the gear and thereby prevent any motion of the wheels.
- There is very unlikely possibility that the wheels themselves no longer index properly.

B. Odometer Calibration

Calibration of the odometer is not as simple as making an adjustment in the works somewhere. Being completely gear driven, you need to replace the gear on the odometer wheel axle that is moved by the pawl. To do this you need the appropriate gear from an otherwise identical speedometer with the proper calibration. The simplest method to do this is to determine what calibration you need. This can be calculated by driving a measured distance of the road. The longer the distance better (ten miles minimum). Then

compare the actual mileage to the indicated mileage. The calibration you will need will be: **Old calibration * indicated Miles / Actual Miles**. If you drive 20 miles and read your odometer to about 1/2 of a tenth, then you will get your correction factor to better than a half a percent and probably close to a quarter of a percent. This is certainly a better calibration than the car had originally.

C. Odometer Styles



The diagram of "old style" main odometer components

"New-Style" Main Odometer

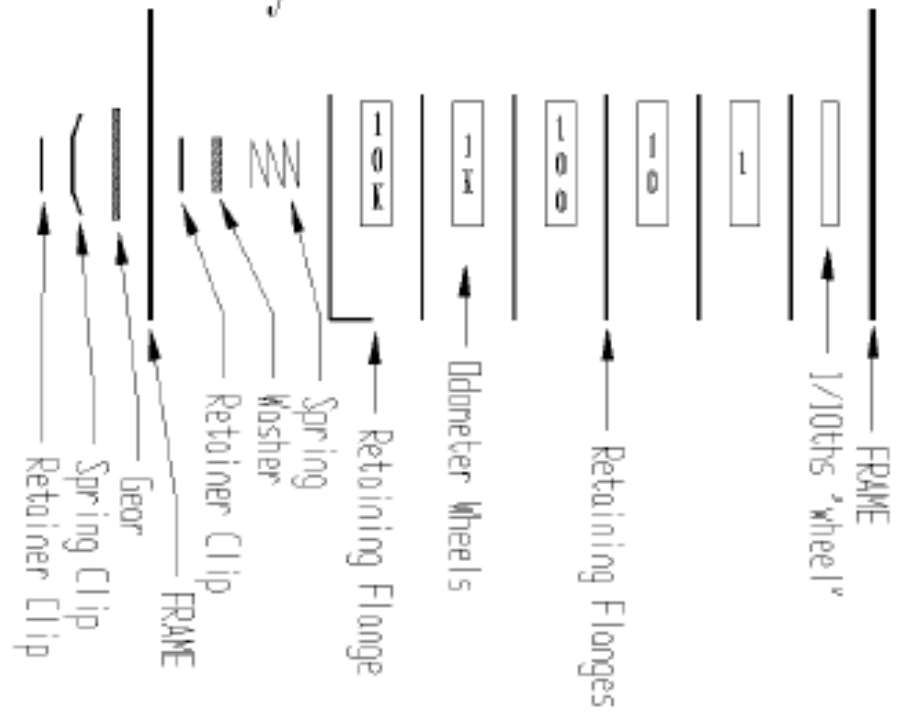
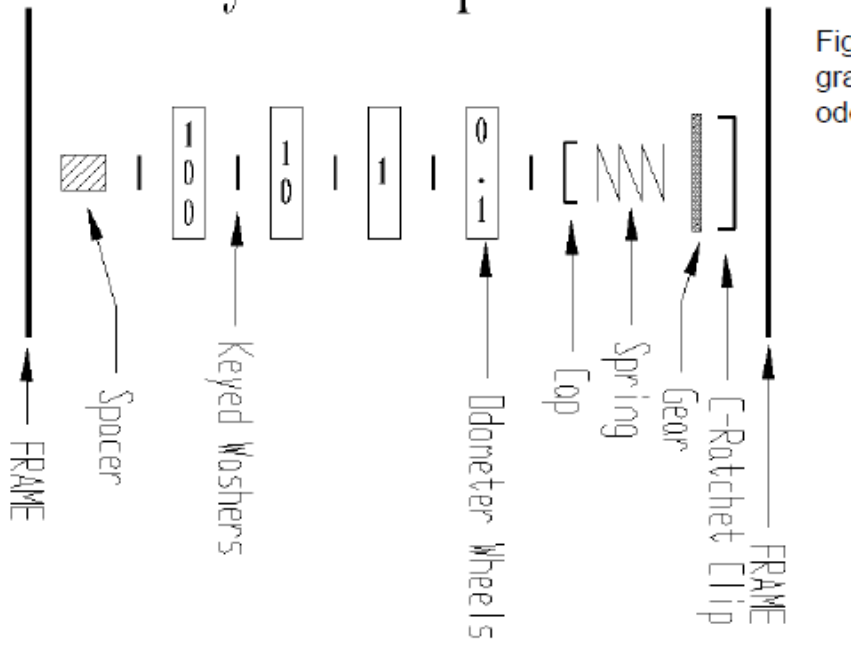


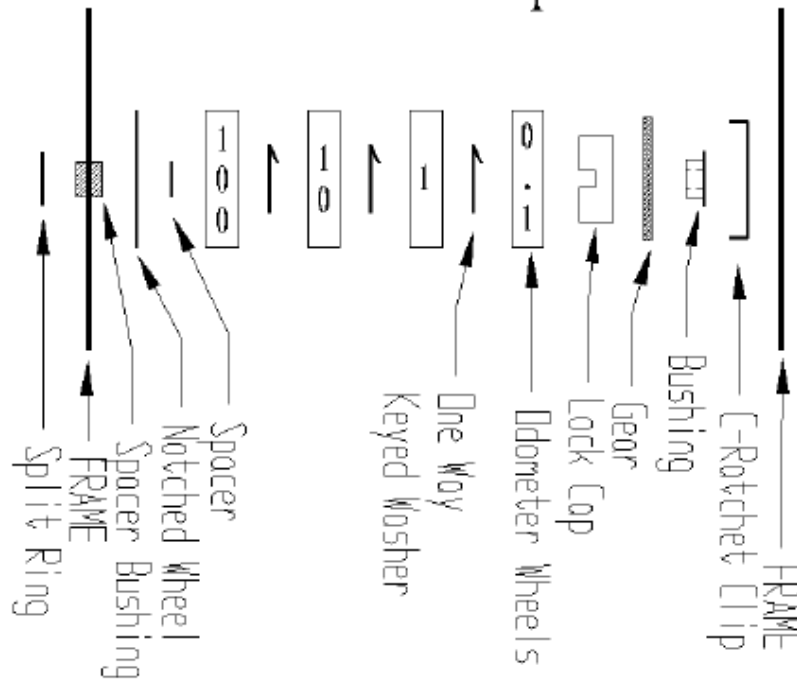
Diagram of "new-style" odometer components

Old-Style Trip Odometer



Exploded diagram of the "Old-style trip odometer"

Intermediate Trip Odometer



Exploded diagram of “Intermediate-style” trip odometer. The “New-style” trip odometer is essentially the same in a different frame.

APPENDIX E

WORM GEAR * ODOMETER GEAR = CALIBRATION

Worm	Odometer	Calibration	Worm	Odometer	Calibration	Worm	Odometer	Calibration
20	50	1000	25	38	950	32	27	864
20	51	1020	25	39	975	32	28	896
20	52	1040	25	40	1000	32	29	928
20	53	1060	25	41	1025	32	30	960
20	54	1080	25	42	1050	32	31	992
20	55	1100	25	43	1075	32	32	1024
20	56	1120	25	44	1100	32	33	1056
20	57	1140	25	45	1125	32	34	1088
20	58	1160	25	46	1150	32	35	1120
20	59	1180	25	47	1175	32	36	1152
20	60	1200	25	48	1200	32	37	1184
20	61	1220	25	49	1225	32	38	1216
20	62	1240	25	50	1250	32	39	1248
20	63	1260	25	51	1275	32	40	1280
20	64	1280	25	52	1300	32	41	1312
20	65	1300	25	53	1325	32	42	1344
20	66	1320	25	54	1350	32	43	1376
20	67	1340	25	55	1375	32	44	1408
20	68	1360	25	56	1400	32	45	1440
20	69	1380	25	57	1425	32	46	1472
20	70	1400	25	58	1450	32	47	1504

If your odometer reads too **MANY** miles: You need **MORE** teeth on the odometer gear. If your odometer reads too **FEW** miles: You need **FEWER** teeth on the odometer gear.

*New Odometer Gear = your odometer gear * your odometer reading/correct odometer reading.* **Note:** you will need to round the answer to the closest whole number.

APPENDIX F

CALCULATION OF TIRE TURNS PER MILE

The number of turns your tire makes when travelling a mile directly influences the speedometer and odometer readings. The speedometer and odometer assume a specific number of turns in a mile. If your tires turn at some other speed, you will induce a measurement error. If the tire size is significantly different, the measurement error will be significant as well. The number of turns per mile is inversely proportional to the tire circumference. The circumference is based upon tread width and aspect ratio as well as the rim diameter. If you make a calculation of the circumference based only on these numbers, you will get the “unloaded” circumference. The loaded circumference is less than that. The industry standard for estimating the loaded versus unloaded difference is 3.1%. The loaded circumference is 3.1% less. Therefore there are about 3.1% more turns per mile than the uncorrected calculation predicts. The actual difference for a particular set of tires will depend on the driving speed, treadwear, and flexibility of the particular tire sidewall. 3.1% is just an average number across many sizes and brands of tires.

$$\text{Overall Diameter}_{\text{inches}} = \text{Rim Diameter}_{\text{inches}} + \frac{\text{Section Width (mm)} \times \text{Aspect ratio (\%)}}{1270}$$

$$\text{No-Load turns per Mile} = \frac{20168}{\text{Overall Diameter (inches)}}$$

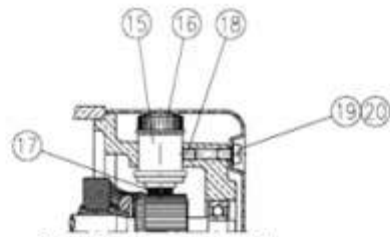
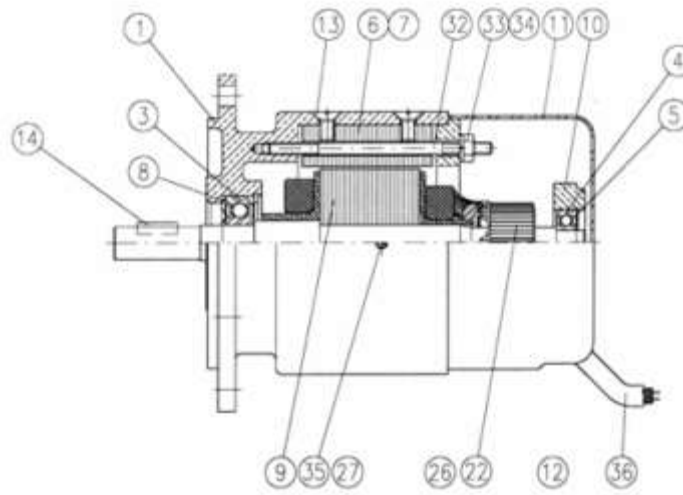
$$\text{Loaded Turns Per Mile} = \frac{20800}{\text{Overall Diameter (inches)}}$$

APPENDIX G

CROSS SECTIONAL DRAWINGS POSITION OF COMPONENTS – 1R (C)

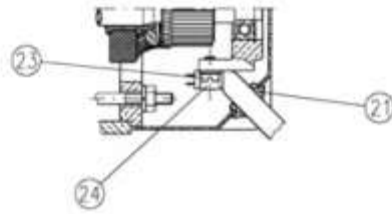
1. Frame – 1R
2. Frame – 1RC
3. Ball bearings – drive end (A.S)
4. Ball bearings – Non drive end (N.S)
5. Retaining ring
6. Pole Core
7. Permanent Magnet
8. Spring rotor
9. Wound rotor
10. Commutator protector cover
11. Protecting cover – 1R
12. Protecting cover – 1RC
13. Fastening ring for pole core
14. Key
15. Branch holder
16. Insulated brush cover
17. Brushes
18. Fastening bolt for brush holder
19. Fastening bolt for protection cover
20. Flat washer
21. Rubber ring for lead passage
22. Commutator
23. Fastening bolt for connection lead
24. Bracket
25. Rubber ring
26. Terminal box cover – 1RC

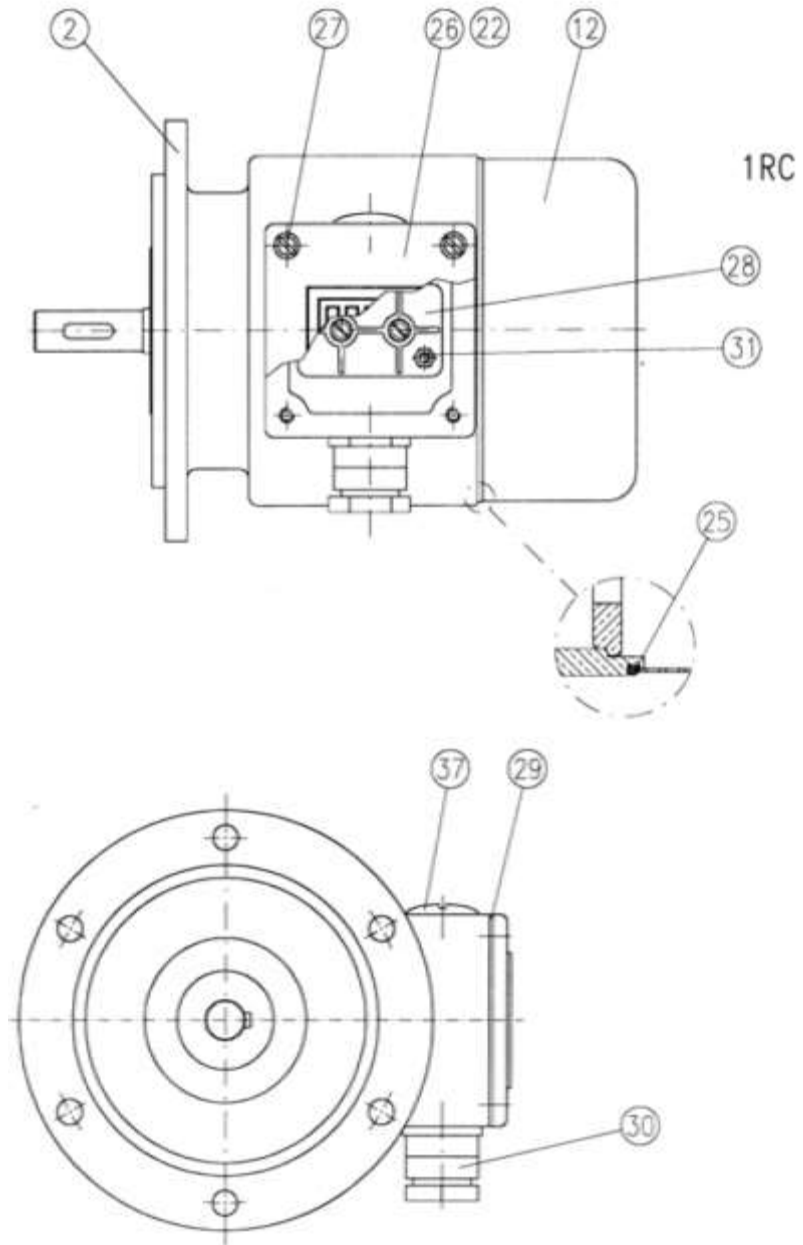
27. Fastening bolt for terminal box
28. Terminal block
29. Rubber gasket
30. Cable gland
31. Fastening bolt for terminal block
32. Through bolt
33. Hexagonal nut
34. Flat washer
35. Fastening bolt for magnet
36. Connection lead
37. Plastic cover



Detail of brush holder

Detail of connection outlet lead





APPENDIX H

1. PLANNED MAINTENANCE: WEEKLY

Components	Inspection or Maintenance Services
Brushes and Bush Holders (1R (C)/ 2RC (P)/ TCW)	<ul style="list-style-type: none"> • Check wear mobility of brushes; • Control the brush wear condition.
Commutator	<ul style="list-style-type: none"> • Check wears and condition of the commutator.

2. PLANNED MAINTENANCE: MONTHLY

Brushes and Bush Holders (1R (C)/ 2RC (P))	<ul style="list-style-type: none"> • Check length of brushes • Replace brushes when wear has reached 2/3 of their size. • Use same or equivalent makes of brushes for replacement. • Check wear and mobility of brushes as well as lead contact and possible breaking. • Remove some brushes and check the contacts on the commutator surface. Dark colouring on the commutator means commutation problems. • Clean the brushes and brush holders to remove the dust coming from the brushes by using a set of dry compressed air.
Brushes and Bush Holders (1R (C)/ 2RC (P)/ TCW)	<ul style="list-style-type: none"> • Check the roughness of the commutator. • Loose brushes cause overheating and excessive wears to the commutator. • Check the rings on the commutator

	<p>surface. If smooth and with no grooves – ok.</p> <ul style="list-style-type: none"> • In case the grooves keep increasing contact the manufacturer. • Check the commutator wear, grooves, copper friction and deformation of the copper plates. • The unround shape of the commutator cannot exceed 0.05mm and the height difference of a copper plate with its adjacent cannot be higher than 0.005mm. If this occurs, the commutator must be machined.
<p>Bolts (1R (C)/ 2RC (P)/ TCW)</p>	<ul style="list-style-type: none"> • Check for loose bolts, parts or electric connections.
<p>Noise and Vibrations</p>	<ul style="list-style-type: none"> • Check terminals and the pressure on the brushes.

PLANNED MAINTENANCE: EVERY THREE (3) MONTHS

<p>Brushes (1R (C)/ 2RC (P)/ TCW)</p>	<ul style="list-style-type: none"> • Check terminals on the brushes.
<p>PLANNED MAINTENACE: EVERY SIX (6) MONTHS</p>	
<p>Bearings (1R (C)/ 2RC (P)</p>	<ul style="list-style-type: none"> • Check all bearings for possible noise.
<p>Commutator (1R (C)/ 2RC (P)/ TCW)</p>	<ul style="list-style-type: none"> • Check the electric connections. • Check if there are bad contacts.
<p>Vibrations (1R ©/ 2RC (P)/ TCW)</p>	<ul style="list-style-type: none"> • Check balancing and alignment of the tachogenerator in relation to the motor to detect possible vibrations.

	<ul style="list-style-type: none"> If vibration cannot be noticed during operation, check the signs which would cause the vibration such as loose parts, dust etc.
--	---

PLANNED MAINTENANCE: ANNUAL

Bearings (1R (C)/ 2RC (P)/ TCW)	<ul style="list-style-type: none"> Perform careful control of bearings. Replace bearings if required.
Cleanliness (1R (C)/ 2RC (P)/ TCW)	<ul style="list-style-type: none"> Clean all the accessible parts of the tachogenerator.

APPENDIX I

TROUBLESHOOTING:

FAILURE	PROBABLE CAUSE	CORRECTIVE MEASURE
---------	----------------	--------------------

Overheating under operation (1R (C)/ 2RC (P)/ TCW)	<ul style="list-style-type: none"> • Short in the armature winding. 	<ul style="list-style-type: none"> • Ship the tachogenerator to the factory.
Overheating of the bearings (1R (C)/ 2RC (P)/ TCW)	<ul style="list-style-type: none"> • Bearings in bad operation condition. 	<ul style="list-style-type: none"> • Replace bearings. • Send the tacho to the factory.
Sparking on the brushes (1R (C)/ 2RC (P)/ TCW)	<ul style="list-style-type: none"> • Bad contact. Particles of impurities get off from the brushes or copper plates and start sparking. 	<ul style="list-style-type: none"> • Set the brushes correctly. • Clean the commutator and all brush devices. • If required, use a different type of brush after getting authorisation from the manufacturer.
Demagnetisation (1R (C)/ 2RC (P)/ TCW)	<ul style="list-style-type: none"> • Short in the armature winding. • Rotor was removed from the frame. • Rapture of the windings armature or commutator places. 	<ul style="list-style-type: none"> • Send the tachogenerator to the factory for repair and magnetisation.
Fluctuations of outgoing voltage (1R (C)/ 2RC (P)/ TCW)	<ul style="list-style-type: none"> • Bad contact of brushes. • Tachogenerator without temperature compensating circuit. • Tachogenerator without compensating 	<ul style="list-style-type: none"> • Set the brushes correctly. • Keep the ambient temperature at 40 degree Celsius or 1000 masl or install temperature

	circuit.	compensating circuit.
Copperplates turned black (1R (C)/ 2RC (P)/ TCW)		<ul style="list-style-type: none">• In this case contact the factory.