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STEERING COUPLER LIFE CYCLE ESTIMATION

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Abstract - The automotive steering column is a device which serves the purpose of connecting the steering wheel with the steering mechanism. Additionally performing auxiliary functions such as energy dissipation management in the event of a frontal collision; provide mounting for column lock, column shrouds, transmission gear selector and also offers height and length adjustment to suit the driver preference. A universal coupling is a component in rigid rod that allows the rod to bend in any direction, and is commonly used in steering column, control mechanisms, aircraft. It is primitively used to transmit rotary motion of a steering wheel to steering gearbox in bent direction. The purpose of manufacturing flexible coupling test rig machine is to determine the life cycle which the coupling can sustain. The coupling is subjected to repeated twisting moment for numerous cycles and based on it life span of steering coupling is calculated. The test is predominantly based on visual inspection as well as results obtained via digital controller display. Various parameters can be adjusted via digital controller which leads to flexibility in machine allowing more exploitation of machine. The machine is capable of testing coupler with different steering column angles.

Key Words: Steering Column, Universal Coupling, Life cycle, Control Mechanism, Column Shrouds, Column Lock.

I. INTRODUCTION OF STEERING SYSTEM

The steering system is an assembly of parts that transmit the movement of the steering wheel to the front, and sometimes the rear wheels. The key purpose of the steering system is to allow the driver to guide the vehicle. When a vehicle is being driven straight ahead, the steering system must provide seamless stability and prohibit it from wandering without demanding the driver to make perpetual corrections.

The steering system must also allow the driver to have some road feel (feedback through the steering wheel about road surface conditions). The steering system must help maintain proper tire-to-road contact. Control of vehicle should be maintained with safety throughout the speed range with little effort and over a wide range of road surfaces under all conditions. The effort by the driver is transmitted through the steering wheel, down the steering column and finally to the steering box.

The rotary motion of the steering wheel is converted into the linear motion required to steer the vehicle with the help of the steering box which also provides the driver with a mechanical advantage. Tie-rods transfers the liner motion, to the steering arms at the front wheels. The tie-rods consist of ball joints which permit movement of the suspension as well as steering, and the steering-arm ball-joints are prearranged in such a fashion that steering operation remains unaffected even after displacement in the suspension assembly.

For maximum tyre life, the steering system should maintain the proper angle between the tyres both during turns and straight-ahead driving. The driver should be able to turn the vehicle with little effort, but not so easily that it is hard to control.

A. *Function of Steering System*

The functions of the steering system are: -

1. It converts the rotary movement of steering wheel into the angular turn of front wheels.
2. It helps in turning the vehicle.
3. It provides directional stability
4. It helps in controlling wear and tear of tyre.
5. It absorbs a leading part of road shocks hence averting them to get transferred to the hand of the driver.
6. Maintain the correct effort needed to turn the wheels. [1]

The steering column in a steering system assist to achieve stability along with steady movement of the vehicle proving to be one of the most vital device of an automobile, the steering yoke, and steering rod of steering column is manufactured with the aid of various processes namely hot forging, machining and assembly by welding [5].

A vehicle steering column assembly consists of components that are responsible for transmitting steering movement across a steering wheel and then to the wheel of a vehicle. The assembly comprises an integrated shaft bearing that links to the steering wheel at one end, a tube assembly interconnected with the integrated shaft bearing at its other end, a yoke assembly having a shaft and being adapted to be interconnected with a lower steering component of the steering system, and a bearing assembly disposed within the

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tube assembly and around the shaft to support the shaft in axial sliding movement within the tube assembly [4].

The steering mechanism permits the driver to tilt the steering wheel for ease during entry or exit. Also when driving, the driver can adjust it at suitable angle, this can be done easily by releasing a lever on the either side of the steering column and fine-tune the wheel into the preferred position, where it can lock itself in a place.

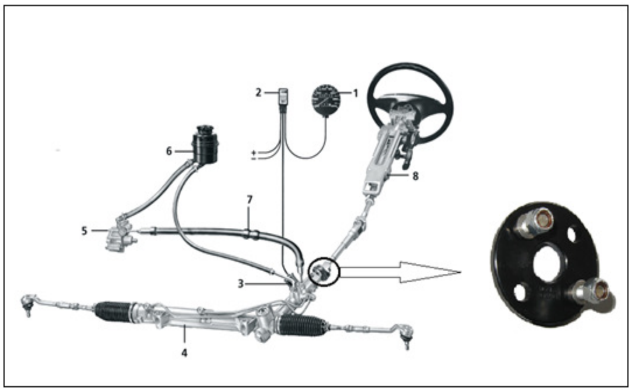

Fig -1: Steering system and coupler

1. Speedometer 2. Battery circuit
3. Return oil line 4. Tie rods
5. Power steering motor 6. Steering oil reservoir
7. Control valve 8. Ignition switch

B. Introduction to Steering Coupler

A coupling is a device which provides functionality of connecting two shafts together at their ends with the intention of transmitting power. Couplings prohibit disconnection of shafts during operation, in contrast when some torque limit is surpassed there are torque limiting couplings which can get dislocated.

The key purpose of couplings is to link two pieces of rotating equipment while allowing certain degree of misalignment, end movement also often both. By watchful selection, installation and maintenance of couplings, significant savings can be augmented in maintenance costs and downtime.

A steering coupling is a coupling in a rigid rod that allows the rod to bend in any direction, and is commonly used in steering column, control mechanisms, aircraft. It is primitively used to transmit rotary motion of a steering wheel to steering gearbox in bent direction.

A steering coupler is generally made of neoprene rubber and it consist of 4 positions, two high and two low positions so as to ensure a perfect steering geometry. One can simulate these positions while turning the steering wheel [3].

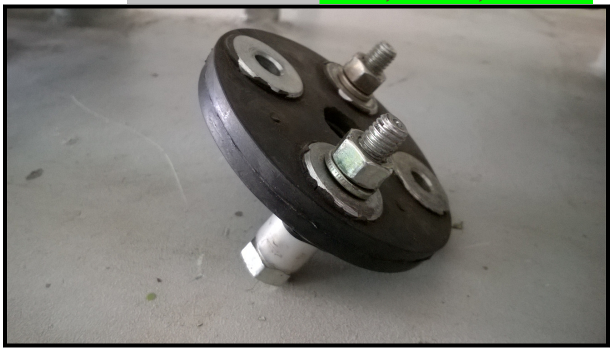

Fig -2: Steering coupler

II. PROBLEM STATEMENT

Steering coupler is one of the most important components in steering system of an automobile. It is commonly experiences torsional stress due to turning of steering wheel and bending stress due to weight of components. Thus, these rotating components are prone to fatigue attributable to nature of their task. Drivers will lose control of their vehicle if the Steering coupler fails during the vehicle operation concerning. Because of this, human life can be in great danger if we don't know when, where and how the coupler will fail. It is very important to know the accurate prediction for the coupler to fail [2].

- ***Aim of Paper***

To offer engineering solution to the component named `Steering Coupler' while addressing functionality of the steering column under varying driving conditions encountered during the service life of the steering coupler and thereby estimating life cycle of steering coupler. During operation the steering coupler should resist all the forces acting on it without producing flaws, failure to this may cause fatal accidents practically.

- ***Objectives***

The main objective of this project work is to quantify the life cycle of the steering coupler by exploiting / examining it on a test. The test would simulate the actual working conditions and the results attained will be close enough to rectify the design of coupler to be safe or not. The test would clinch twisting moment of coupler, its performance and ability to withstand various forces and stresses acting on it.

This can be accomplished with the help of Flexible Coupling Test rig. Flexible Coupling Test Rig simulates actual working steering condition and thus allows customer to know the exact life span of coupler.

III. METHODOLOGY

The steering system was precisely studied in order to simulate the exact arrangement on the test rig. Every component was thoroughly studied so as to place an alternative on the machine for precise calculation. In order to apply the torque experienced by the steering system a band brake assembly was incorporated. To measure the torque and to control it, a rotary torque sensor coalesced with machine along with its display unit. Placement of proximity sensor near to steering yoke ensured exact rotation calculation which is coupled to electronic display panel.

A) Design of Steering Shaft (Input):-

Given Data:

P= 1.5 HP

W= 30 kg

$$P = \frac{2\pi NT}{60}$$

$$\frac{1.50}{746} = \frac{2*\pi*50*T}{60}$$

T = 213.71 N-m.

T = 213.71 x 10^3 N-mm

By using formula,

$$T = \frac{\pi}{16} d^3$$

$$213.71 \times 10^3 = \frac{\pi}{16} d^3$$

d = 29.59 mm.

d= 35 mm. …… (As per Standard)

According to Maximum Shear Stress Theory:-

M= W*L

When,

W= 30 kg, L=144mm

M = 30 *9.81 *144

M = 42.3792 x 10^3N-mm

By using formula,

$$\sigma b = \frac{32*M}{\pi d^3}$$

$$= \frac{32*42.3792*10^3}{\pi*35^3}$$

σb = 10.068 N/mm^2.

By using formula,

$$\tau = \frac{16*T}{\pi d^3}$$

$$= \frac{16*213.71*10^3}{\pi*35^3}$$

τ = 25.38 N/mm^2.

According to Maximum shear stress Theory:-

$$\tau max = \frac{1}{2}\sqrt{\sigma_b^2 + 4\tau^2}$$

τ_{max}= 25.874N/mm^2.

According to maximum Normal Stress,

$$\sigma bmax = \frac{1}{2}\sigma b + \tau max$$

$$= \frac{1}{2}\ (10.068) + 25.87$$

σbmax =30.908 N/mm^2.

Torsional stress or Twisting moment:-

$$Te = \sqrt{M^2 + T^2}$$

$$= \sqrt{423792^2 + 213710^2}$$

Te =474.627 x 10^3 N-mm.

B) Design of Steering Shaft (Output):-

The values determined are as follows:

Design of shaft :-

Given Data:

P= 1.5 HP

W= 20 kg

$$P = \frac{2\pi NT}{60}$$

$$\frac{1.50}{746} = \frac{2*\pi*50*T}{60}$$

T = 213.71 N-m.

T = 213.71 x 10^3 N-mm.

By using formula,

$$T = \frac{\pi}{16} d^3$$

$$213.71 \times 10^3 = \frac{\pi}{16} d^3$$

d = 29.59 mm.

d = 35 mm. …… (As per Standard)

According to Maximum Shear Stress Theory:-

M = W*L

When,

W= 20 kg, L=144mm

M = 20 * 9.81 *144

M = 28252.8 x 10^3 N-mm

By using formula,

$$\sigma b = \frac{32*M}{\pi d^3}$$

$$= \frac{32*42.3792*10^3}{\pi*35^3}$$

σb = 6.71206N/mm^2.

By using formula,

$$\tau = \frac{16*T}{\pi d^3}$$

$$= \frac{16*213.71*10^3}{\pi*35^3}$$

τ = 25.38 N/mm^2.

According to Maximum shear stress Theory:-

$$\tau max = \frac{1}{2}\sqrt{\sigma_b^2 + 4\tau^2}$$

$$= \frac{1}{2}\sqrt{6.7120^2 + 4 \times 25.38^2}$$

τ_{max} = 25.6009 N/mm^2.

According to maximum Normal Stress,

$$\sigma bmax = \frac{1}{2}\ \sigma b + \tau max$$

$$= \frac{1}{2}\ (6.7120 + 25.60)$$

σbmax = 16.15 N/mm^2.

Torsional stress or Twisting moment:-

$$Te = \sqrt{M^2 + T^2}$$

$$= \sqrt{28252.8^2 + 213710^2}$$

Te = 215.56 x 10^3 N-mm.

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C) Use of AutoCAD

Prototyping**: -** Prototyping can be an extensive and laborious job, especially in a multifaceted field like mechanical engineering where the number of variables and moving parts and repeated design tests are essential. AutoCAD allows mechanical engineers to shorten this process by including simulations of how products will operate under certain conditions. Mechanical engineers, therefore, can see the effects of changes in materials and dimensions by simply entering new data into the model, rather than physically testing iterations of the design.

Drafting of components**: -** Drafting is primary stage in manufacturing which provides a precise medium to outline a component at its best, thus permitting the manufacturer to concept the component near to its design. Various parts were designed and drafted verifying whether the design is practicable. Drafting allows alterations in the design related to the system before it is laid to definite manufacturing. Drafting will also aid in designing the components at ease and validate the compatibility of the designed components, eliminating the necessity of actual manufacturing of a false component, resulting in saved time, money & efforts.

D) Drafting of Various Components:-

i. Steering coupler.
ii. Universal coupling.
iii. Shaft

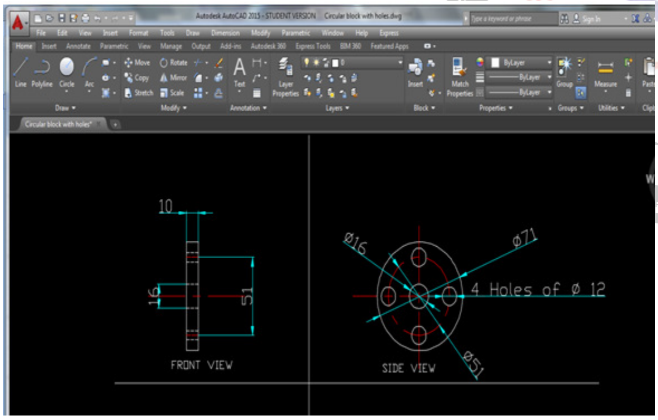


Fig -3: Steering coupler (draft view)

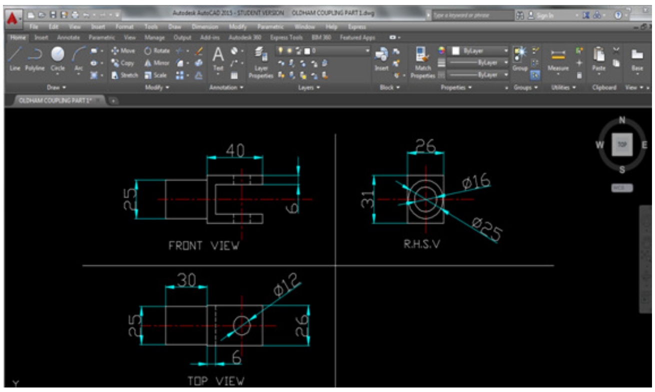


Fig -4: Universal coupling

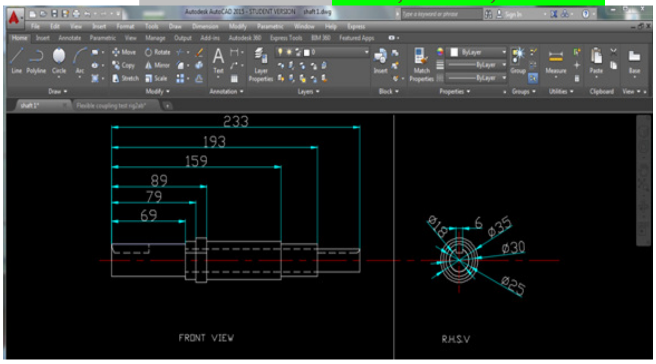


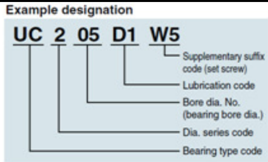
Fig -5: Shaft

IV. SELECTION OF STANDARD PARTS

A) Ball Bearing Part Number

i. Bearing internal clearance is nominal bearing
ii. Bore diameter should be >30 and <40.
iii. Radial clearance Class 2: 1 (min), 11 (max).
iv. Nominal clearance: 6 (min), 20 (max).
As per manufacturer's catalogue the selected bearing is
UC 2 07 D1 W3

Example designation



Diameter series code

Series 2	Light load
Series X	Medium load
Series 3	Heavy load

Bore code number and bore diameter

#00	10mm (CS200LLU)
#01	12mm
#02	15mm
#03	17mm
For bore dia. of #04 and above, bore code No. multiplied by 5.	

Bearing type code

UC (JIS)	Spherical outside face, cylindrical bore (w/set screws)
UK (JIS)	Spherical outside face, tapered bore (adapter type)
AS	UC type, minus flinger (LLU type)
CS	Rubber sealed type, inner and outer ring widths equal.
UEL (JIS)	UC type w/eccentric collar
AEL (JIS)	UEL type, minus flinger (LLU type)
UCSXXXN	UC type, straight outer face (w/set screws)
UKSXXXN	UK type, straight outer face (adapter type)
ASSXXXN	AS type, straight outer face
UELSXXXN	UEL type, straight outer face
AELSXXXN	AEL type, straight outer face

Note: No lubrication code is included in part number of other manufacturers' products, since their products are lubricated as standard.

Supplementary suffix code (set screws)

No code	w/2 ball-point set screws (mm): standard products w/mm size bore
No code	w/2 ball-point set screws (inch): standard products w/inch size bore
W5	w/hex. socket head cap dog point set screw W55: w/2 pcs.
W6	w/hex. socket head cap key bolt set screw W66: w/ 2 pcs.
W7-n	w/2 special set screws

Fig -6: Standard table for ball bearing

B. Selection of Jaw Coupling

JAW COUPLINGS:
SERVICE FACTORS:

Type of Driven Machine	Type of Driving Unit		
	Electric Motors & Steam Turbines	Internal Combustion Engines	
		More than six cylinders	Less than six cylinders
Uniform Load Agitators, Brewing machinery, Centrifugal compressors and pumps, Belt conveyors, Dynamometers, Lineshafts, Fans upto 7.5 kW, Blowers and exhausters except positive displacement, Generators.	1.0	1.5	2.0
Moderate Shock Clay working machinery, General machine tools, Paper mill beaters and winders, Rotary pumps, Rubber extruders, Rotary screens, Textile machinery, Marine propellers and fans over 7.5 kW.	1.5	2.0	2.5
Heavy Shock Bucket elevators, Cooling tower fans, Piston compressors and pumps, Foundry machinery, Metal presses, Paper mill calenders, Hammer mills, Presses and pulp grinders, Rubber calenders, Pulverisers and positive displacement blowers.	2.0	2.5	3.0

Fig -7: Service factor selection for jaw coupling

Selection of standard jaw coupling:

i. Select the service factor from the above table.
ii. Multiply the service factor with the power requirement.

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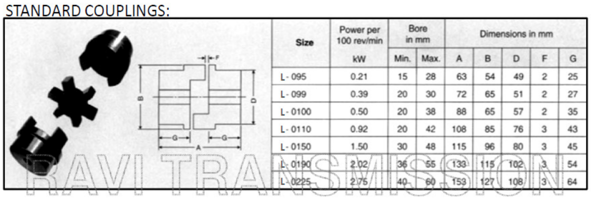
iii. From the below table L-0100 standard jaw coupling is selected and its corresponding dimensions are also given.


STANDARD COUPLINGS:

Size	Power per 100 rev/min	Bore in mm		Dimensions in mm				
	kW	Min.	Max.	A	B	D	F	G
L-095	0.21	15	28	63	54	49	2	25
L-099	0.39	20	30	72	65	51	2	27
L-0100	0.50	20	38	88	65	57	2	35
L-0110	0.92	20	42	108	85	76	3	43
L-0150	1.50	30	48	115	96	80	3	45
L-0190	2.02	36	55	133	115	102	3	54
L-0225	2.75	40	60	153	127	108	3	64

Fig -8: Standard table for jaw coupling

C. Supplementary Parts of Test Rig:

1. D.C.Shunt Motor (1.5 HP)
2. Reduction gear box (24:1)
3. Proximity sensor
4. Rotary torque sensor
5. Electronic control panel
6. Band brake

D. Logical View of Test Rig:

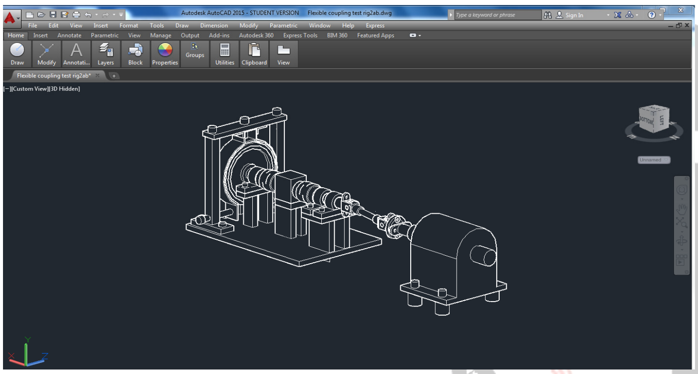


Fig -9: Logical view of FLEXIBLE COUPLING TEST RIG

V. EXPERIMENTAL SETUP FOR TESTING STEERING COUPLER

The objective of current work is to determine the life cycle of steering coupler. The experimentation carried over the model of flexible coupling test rig is compared to the value of life cycle given by the customer. The rotary torque sensor and the infrared sensor will check for proper torque and the rudimentary stages of crack.

The setup consist of a motor which is of 1.5 HP, Oldham's coupling which are two in quantity and are used primitively to transmit the power in bent axis. Further pillow block bearings are attached which are four in number and are particularly used to support the shaft and carry out balancing. The jaw coupling is provided to reduce the vibration. The band brake assembly is coupled to apply the required torque.

This complete assembly would simulate the actual condition of a steering mechanism and precise results can be tabulated. The assembly is flexible at the angle adjustment which in turn would provide testing of different couplers specified at different angles which are provided by customer.

A. Actual Machine Layout

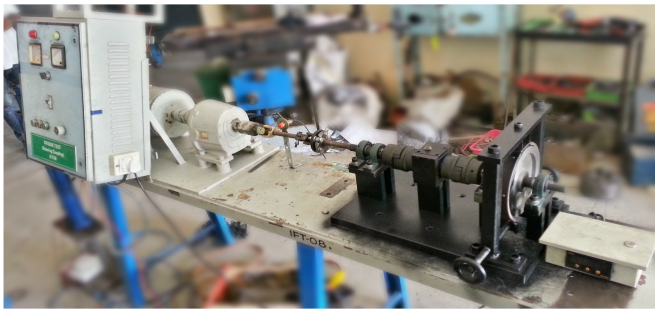


Fig-10: Actual view of FLEXIBLE COUPLING TEST RIG

B. Test Procedure: -

Aim: - To calculate the life cycle of steering coupler for its acceptance or rejection.

Procedure: -

i. The manufacturer's catalogue is studied in order to verify the number of cycles to be completed by coupler with a specific speed and torque.
ii. The electronic control panel is incorporated in order to start the machine and control its various parameters viz. speed, motion.
iii. The required torque is calibrated via band brake assembly while the excess torque is controlled by rotary torque sensor.
iv. The proximity sensor is switched ON so as to calculate the cycles which are displayed on cycle calculator display.
v. The proximity sensing ensures proper working of the test rig.
vi. In case the torque decreases due to flaw generation the torque sensor will send the signal to electronic panel, which will cut OFF the main power supply.
vii. This ensures partial safety to machine.

Table -1: Observation Table

Cycles	RPM	Time for each cycle (Hours)	Observation	Remark
10,000	10	16	No cracks detected	Safe
20,000	10	33	No cracks detected	Safe
40,000	10	66	No cracks detected	Safe
60,000	10	100	No cracks detected	Safe
80,000	10	133	No cracks detected	Safe
1,00,000	10	166	No cracks detected	Safe

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C. Results

Sr. No	Name: Steering Coupler Life Cycle Estimation Test type: Torsional Durability
1. 2.	Objective: To check rubber coupling durability in torsional loading. Part Detail: Rubber coupling or Steering coupling I.D. : 17mm O.D. : 74mm Car used: Tata Indica.
	
3. 4. 5.	Test condition: i. Torque Applied : ±29.4 N.m ii. Joint Angle: 29°. (car steering angle) iii. Joint Rotating angle: ± 180°. iv. Test Cycles: 1, 00,000 cycles. Acceptance ratio: No breakage or crack observed. Comment: Part is OK.

D. Pros and Cons

Pros:-

i. Machine is capable of resisting torque up to 200 N-m.
ii. Use of electronic control panel provides with a wider range of speeds and motion.
iii. Less human intervention.
iv. Torque can be precisely controlled with help of torque sensor.
v. High efficiency of machine since power loss is less.
vi. Band brake ensures proper torque application.
vii. Reliability of machine is good.

Cons:-

i. Cost of machine is high.
ii. Angle measurement sensor is not available.
iii. Frequent inspection is required.
iv. No sensor for detecting human intervention while in operation.

VI. CONCLUSION

The experimentation led us to the outcome of estimation of life cycle of the steering coupler, the engineered machine was able to estimate the precise life cycle of steering coupler which in turn amplified the dependency on machine.

The test specimen used was found to be safe under certain conditions and performed accurately under estimated life cycle thereby conforming safety of component and steering architecture as whole.

VII. FUTURE SCOPE

As the empiricism was undertaken and inspection was done on the life cycle of steering coupler in context to steering coupler test rig, so the future scope will be:

1. The Flexible coupler test rig which is restricted to light motor vehicle coupler test could also be tested on heavy vehicles with certain plug and play adjustments.
2. The rig can be automated by installing programmed controllers which will consecutively adjust the motor and torque generating device required for specific applications.
3. The current flaw detection involves human intervention at certain time interval. This can be expelled by using ultrasonic, infrared wave sensors.
4. The angle adaption can also be designed, as heavy vehicles incur different steering angle.
5. With the help of PLC and SCADA programmable systems we can plot different characteristics of system graphically.

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