

Dynamic Analysis of Lobe Coupling by Formulation of an Approximate Generalized Experimental Data Based Model

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Abstract- This paper presents an approach to establish operational characteristics of ball joint-lobe type coupling by performing extensive experimentation. This experimentation is performed by changing independent physical quantities of the coupling over a wide range and response data is gathered. Based on the response data, the mathematical model is formulated correlating the responses in terms of independent variables. These models can be used as a design data for this coupling. Because of complexity in kinematics and dynamics of coupling, logic based modeling is difficult for this type of coupling. This type of coupling is mainly used in harvester. Thus, this research outcome is useful in the design of mechanical transmission system of harvester. An emphasis is laid on the study of response of the coupling towards the variation in misalignment.

Index Terms- Angular Misalignment, Ball Joint- Lobe type Coupling, Brake Dynamometer, Grain Combine Harvester, Opto-coupler.

I. INTRODUCTION

During the past few years in the drive of a grain combine harvester SK5 'Niva', a gear coupling is used to transmit the adequate torque and speed. The design of drive is good from production engineering aspects for manufacture and assembly but it is not reliable enough to provide longer service life of coupling because of toothed coupling and it does not accept the required range of angular misalignment. P. A. Kargin [1] has for the first time introduced a new type of flexible coupling named "Hinge joint – Lobe coupling". It is recommended to adopt this coupling on grain combine harvester. In this machine there are chances of considerable misalignment getting induced in its operation. D.N. Reshetoveta [2] introduced a flexible coupling with elastic elements in the form of lobes are widely used for connecting shafts with significant relative misalignment but insufficient to provide sufficient compensation for angular misalignment.

The paper [1] and future literature on couplings after performing proper survey is not seen to contain design data. Therefore, the design of such type of coupling for various specifications of grain combine harvesters is not possible. In present research, it is proposed to generate design data based on operational characteristics of this new type of coupling.

II. APPROACH FOR PROBLEM SOLUTION

The specific objectives of present investigation are as under:

- 1) To establish steady state operational characteristics of this coupling.
- 2) To generate design data of this type of coupling

This design data will be in the form of evolving experimental data based models, H.Schanck,Jr.[3] for various responses of this type of coupling. These responses are Input Power, Driving Torque, Torque Transmission Efficiency and Rise in Temperature of Lubricant.

A. Design of Experimentation

It involves (i) Identification of Independent and Response variables which directly affect the torque transmission (ii) Establishing dimensional equations for this new type of coupling, the loading system and energy feeding system, (iii) Test planning for the involved dimensional equations, which includes Test envelope, Deciding Test points, Deciding Test Sequence and Deciding Plan of experimentation.

Table I: various independent & response variables with their symbols, nomenclature & dimensions.

Independent Variables				
S/N	Nomenclature	Symbols	Units	Dimensions
1	Speed	N	rps	$M^0 L^0 T^{-1}$
2	Load Torque	TL	N-m	$M^1 L^2 T^{-2}$
3	Angular Misalignment	Mang	rad	$M^0 L^0 T^0$
4	Outside Diameter of Hub	Dho	m	$M^0 L^1 T^0$
5	Inside Diameter of Hub	Dhi	m	$M^0 L^1 T^0$
6	Outside Diameter of Flange	Fo	m	$M^0 L^1 T^0$
7	Thickness of Flange	Ft	m	$M^0 L^1 T^0$
8	Length of Hub	Lh	m	$M^0 L^1 T^0$
9	No of Lobes	ln	m	$M^0 L^0 T^0$
10	Length of Lobe	ll	m	$M^0 L^1 T^0$
11	Breadth of Lobe	lb	m	$M^0 L^1 T^0$
12	Thickness of Lobe	lt	m	$M^0 L^1 T^0$

13	Ball Diameter	Db	m	$M^0L^1T^0$
14	Viscosity of Lubricant	μ	$\frac{N}{s/m^2}$	$M^1L^{-1}T^{-1}$
15	Operational Time	t_o	sec	$M^0L^0T^1$
16	Density of Materials	ρ	Kg/m^3	$M^1L^{-3}T^0$
17	Initial Temperature of lubricant	θ_a	$^{\circ}C$	$M^0L^0T^0\theta^1$
Dependent Variables				
1	Input Power	Pin	watts	$M^1L^2T^{-3}$
2	Driving Torque	Td	N-m	$M^1L^2T^{-2}$
3	Torque Transmission Efficiency	η	--	$M^0L^0T^0$
4	Rise of Temperature of Lubricant	$\Delta\theta$	$^{\circ}C$	$M^0L^0T^0\theta^1$

III. EXPERIMENTATION

A classical plan of experimentation consists of holding all but one of the independent variable constant and changing this one variable over its range. While changing one of the independent variables over its range, other independent variables are set at its mean value.

A. DESIGN OF AN EXPERIMENTAL SET UP

It is necessary to evolve physical design of an experimental set up having provision of setting test points, adjusting test sequence, executing proposed experimental plan, provision for necessary instrumentation for noting down the responses and independent variables, Figure 1 shows the photograph of experimental setup used for the experimentation & Figure 2 shows the photograph of Ball Joint-Lobe Coupling.



Figure 1: Photograph of experimental setup.



Figure 2: Photograph of Ball Joint-Lobe Coupling

Shaft Diameter Calculation:

Input power is supplied from 3.7 kW, 3- Phase, 4- Pole, Squirrel Cage Induction Motor of 1450 rpm.

For maximum power transmission, it is considered to take maximum power and minimum speed.

For 3.7 kW and 100 rpm, maximum torque transmitted through the coupling.

$$i.e. T_d = 60 \times P_i / 2 \pi N,$$

$$\text{Since } P_i = 2 \pi N T_d / 60,$$

where N- speed in rpm

$$T_d = 353.5 \text{ N-m.}$$

$$T_d = \pi / 16 \times f_s d^3$$

Where f_s = Permissible shear stress

$$= 42 \times 10^6 \text{ N/m}^2$$

$$353.5 = \pi / 16 \times 42 \times 10^6 d^3$$

$$\therefore d = 35 \text{ mm}$$

= Diameter of Shaft

Other Geometrical Parameters of the Coupling:

Hub outside diameter, $D_{ho} = 1.75d + 30 \text{ mm}$

$$= 1.75 \times 35 + 30 = 91.25 \text{ mm} \approx 95 \text{ mm}$$

Hub inside diameter,

$$D_{hi} = \text{Diameter of shaft} = 35 \text{ mm}$$

Ball Diameter, $D_b = 45 \text{ mm}$

Hub length, $L_h = 1.25d + 20 \text{ mm}$

$$= 1.25 \times 35 + 20$$

$$= 63.75 \text{ mm} \approx 60 \text{ mm}$$

Flange outside diameter of half couplings,

$$F_o = 4d = 4 \times 35 = 140 \text{ mm} \approx 150 \text{ mm}$$

Flange thickness,

$$F_t = 1/2d = 1/2 \times 35 = 17.5 \text{ mm} \approx 25 \text{ mm}$$

Brake Drum Diameter = 300 mm.

Lobe dimensions: Since this is a new type of coupling and how it behaves for the different dimensions of lobes which are chosen, that is to be studied.

First set of lobes: Length of lobe, $l_l = 80 \text{ mm}$,

Breadth of lobe, $l_b = 15 \text{ mm}$,

Thickness of lobe, $l_t = 15 \text{ mm}$

Second set of lobes: Length of lobe, $l_l = 80 \text{ mm}$,

Breadth of lobe, $l_b = 20 \text{ mm}$,

Thickness of lobe, $l_t = 20 \text{ mm}$

Third set of lobes: Length of lobe, $l_l=80\text{mm}$,
Breadth of lobe, $l_b=22\text{mm}$,
Thickness of lobe, $l_t=22\text{mm}$
Fourth set of lobes: Length of lobe, $l_l=80\text{mm}$,
Breadth of lobe, $l_b=25\text{mm}$,
Thickness of lobe, $l_t=25\text{mm}$

The working faces of the lobes are made flat and their demanded contact is achieved as running-in proceeds. Experimentation is carried out at four different levels of speed i.e. 100rpm, 150rpm, 225rpm, and 300rpm. In order to achieve required speed, gear box having different gear ratios i.e. 14.5:1, 9.67:1, 6.44:1, and 4.83 :1 respectively is used , as motor shaft speed is 1450rpm.

B. DESIGN OF INSTRUMENTATION FOR MEASUREMENT OF INDEPENDENT AND RESPONSE VARIABLES

For linear measurements, vernier caliper is used. Angular measurement is done graphically. Load torque is measured with the help of Brake Dynamometer. Input power of the motor can be calculated by measuring Current (I) using current transformer (Turns Ratio 30/5),Voltage (V) using potential transformer, and power factor (Cos Φ) by power factor meter (voltage 250-500 Volts , Current 10-20 Ampere). The slotted Opto-coupler is used for measurement of speed. Temperature of lubricant is measured by temperature sensor. Real Time Clock displays the operational time. The output of all these sensors is directly connected to LCD Display through Microcontroller.

C. FORMULATION OF MATHEMATICAL MODEL

The various mathematical models for different dependent Pi terms are stated below:

For Input Power:

$$Pi\ 01 = 250.72547 \times \pi_1^{0.48197} \pi_2^{0.03766} \pi_3^{0.05659} \pi_4^{0.03944} \pi_5^{0.09727}$$

$$P_{in} / \rho N^3 D_b^5 = 250.72547 [T_L \mu g / \rho^2 N^5 D_b^8]^{0.48197} [M_{ang}]^{0.03766} [D_{ho} D_{hi} L_h F_o F_t l_l l_b l_t / D_b^8]^{0.05659} [l_n]^{0.03944} [Nt_0]^{0.09727}$$

For Driving Torque:

$$Pi\ 02 = 39.88814 \times \pi_1^{0.482} \pi_2^{0.038} \pi_3^{0.057} \pi_4^{0.039} \pi_5^{0.097}$$

$$T_d / \rho N^2 D_b^5 = 39.88814 [T_L \mu g / \rho^2 N^5 D_b^8]^{0.482} [M_{ang}]^{0.038} [D_{ho} D_{hi} L_h F_o F_t l_l l_b l_t / D_b^8]^{0.057} [l_n]^{0.039} [Nt_0]^{0.097}$$

For Torque Transmission Efficiency:

$$Pi\ 03 = 250.72547 \times \pi_1^{-0.05003} \pi_2^{0.03766} \pi_3^{-0.05502} \pi_4^{-0.03421} \pi_5^{0.00881}$$

$$\eta = 95.76209 [T_L \mu g / \rho^2 N^5 D_b^8]^{-0.05003} [M_{ang}]^{-0.04363} [D_{ho} D_{hi} L_h F_o F_t l_l l_b l_t / D_b^8]^{-0.05502} [l_n]^{-0.03421} [Nt_0]^{0.00881}$$

For Rise in temperature of Lubricant:

$$Pi\ 04 = 250.72547 \times \pi_1^{-0.00436} \pi_2^{0.34344} \pi_3^{-0.02611} \pi_4^{-0.04225} \pi_5^{0.49523}$$

$$\Delta\theta / \theta_a = 0.00059 [T_L \mu g / \rho^2 N^5 D_b^8]^{0.00436} [M_{ang}]^{0.34344} [D_{ho} D_{hi} L_h F_o F_t l_l l_b l_t / D_b^8]^{-0.02611} [l_n]^{-0.04225} [Nt_0]^{0.49523}$$

3.4 MODEL FORMULATION IN ANN

The phenomenon of dynamics of coupling is complicated and is having high non linearity so model formulation is also done

using Artificial Neural Network (ANN) in order to reduce the error. The output of this network can be evaluated by comparing it with experimental data and the data calculated from the mathematical models.

The following graphs (Fig. 3, 4, 5 & 6) shows the comparison between dependant pi-terms for response variables i.e. Input Power, Driving Torque, Torque Transmission Efficiency and Rise in temperature of lubricant verses product of five independent pi-terms, viz. $\pi_1 = T_L \mu g / \rho^2 N^5 D_b^8$, $\pi_2 = M_{ang}$, $\pi_3 = D_{ho}$, D_{hi} , L_h , F_o , F_t , l_l , l_b , l_t / D_b^8 , $\pi_4 = l_n$, & $\pi_5 = Nt_0$.

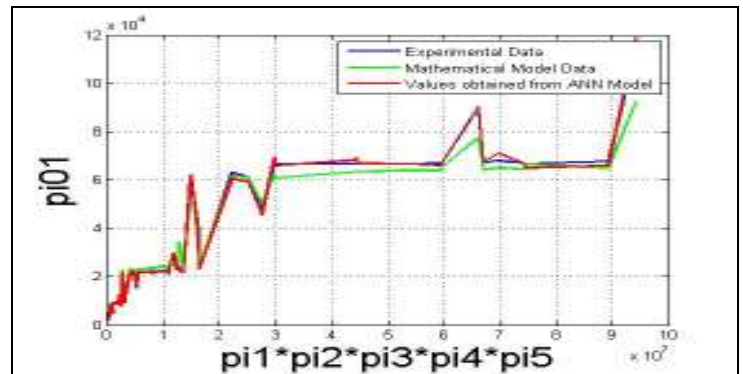


Figure 3: Comparison Plot of PI-01 for Experimental Data, Mathematical Model & ANN Model

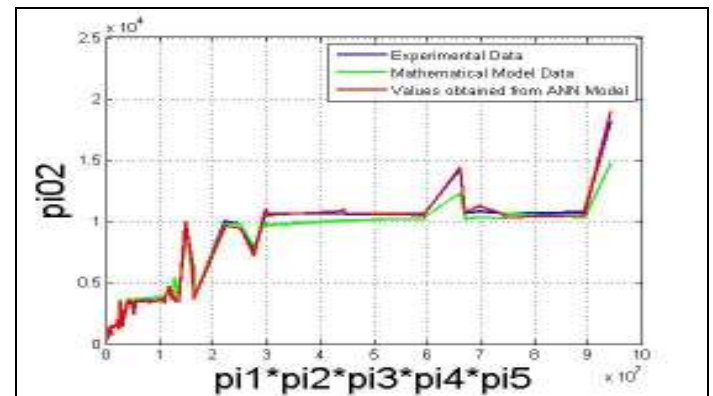


Figure 4: Comparison Plot of PI-02 for Experimental Data, Mathematical Model & ANN Model

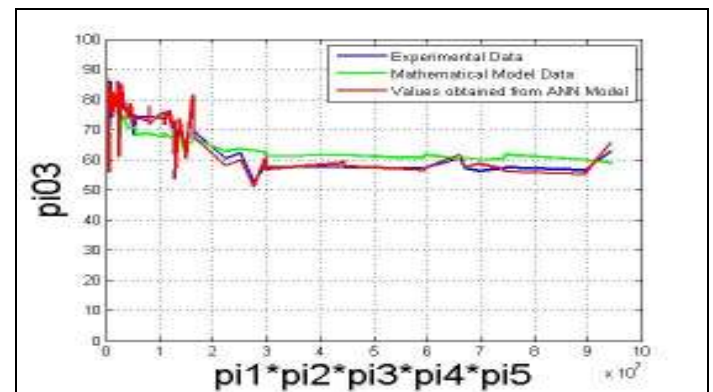


Figure 5: Comparison Plot of PI-03 for Experimental Data, Mathematical Model & ANN Model

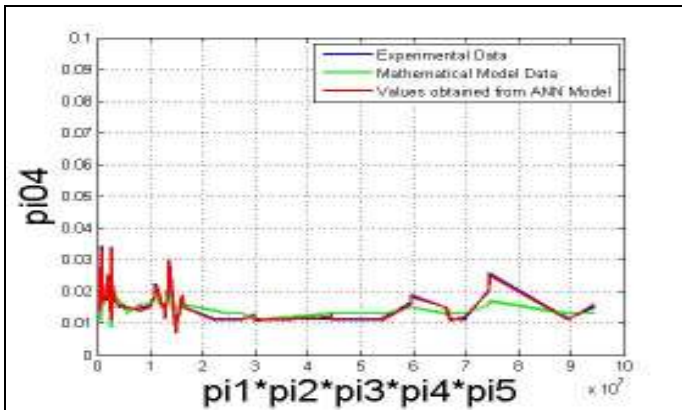


Figure 6: Comparison Plot of PI-04 for Experimental Data, Mathematical Model & ANN Model

IV. DISCUSSION OF RESULTS

With the help of experimental data of a Ball joint- Lobe type flexible coupling, the models are analyzed qualitatively for response variable viz. Input power, Driving Torque, Torque Transmission Efficiency, and Rise in Temperature of lubricant. Models have been formed for the above dependent pi-terms and its values are computed with the product of independent pi-terms. It can be observed from the graphs, the complex trend of variation of response variables with the product of independent pi-terms. With the rise of Input power, the Torque Transmission Efficiency is non-linearly & exponentially dropping with minor fluctuations in the Rise of temperature of lubricant.

An attempt has been made for the quantitative analysis of the model for all response variables during experimentation. The indices of the models are the indicator of how the phenomenon is getting affected because of interaction of various independent pi-terms in the models.

The model for the first response variable i.e. Input Power (Pi 01) is:

$$P_{in}/\rho N^3 D_b^5 = 250.72547 [T_L \mu g/\rho^2 N^5 D_b^8]^{0.48197} [M_{ang}]^{0.03766} [D_{ho} D_{hi} L_h F_o F_t l_b l_t/D_b^8]^{0.05659} [l_n]^{0.03944} [Nt_0]^{0.09727}$$

The absolute index of the pi term $[T_L \mu g/\rho^2 N^5 D_b^8]$ is high, viz.0.48197, it indicates that its influence on Input Power is high & responsible independent variable for this influence is load torque as other independent variables are constant. The absolute index of the pi term $[M_{ang}]$ is low, viz. 0.03766, it indicates that its influence on Input Power is less or in other words angular misalignment does not affect much on Input Power. The absolute indices of the other pi terms (which are mainly related with geometrical parameters of the coupling and lobes, number of lobes and speed), are moderate influences moderately on Input power. The curve fitting constant being greater than one shows the effect of some additional response variables which might not

be considered in the phenomena, it may be contact stresses produced at the mating parts of the lobes, wear at ball joint, etc.

The model for the second response variable i.e. Driving torque (Pi 02) is:

$$T_d/\rho N^2 D_b^5 = 39.88814 [T_L \mu g/\rho^2 N^5 D_b^8]^{0.482} [M_{ang}]^{0.038} [D_{ho} D_{hi} L_h F_o F_t l_b l_t/D_b^8]^{0.057} [l_n]^{0.039} [Nt_0]^{0.097}$$

The absolute index of the pi term $[T_L \mu g/\rho^2 N^5 D_b^8]$ is high, viz.0.482, it indicates that its influence on Driving Torque is high & responsible independent variable for this influence is load torque as other independent variables are constant. The absolute index of the pi term $[M_{ang}]$ is low, viz. 0.038, it indicates that its influence on Driving Torque is less or in other words angular misalignment does not affect much on Driving Torque. The absolute indices of the other pi terms (which are mainly related with geometrical parameters of the coupling and lobes, number of lobes and speed), are moderate influences moderately on Driving Torque. The curve fitting constant being greater than one shows the effect of some additional response variables which might not be considered in the phenomena, it may be contact stresses produced at the mating parts of the lobes, wear at ball joint, etc.

The model for the Third response variable i.e Torque Transmission Efficiency (Pi 03) is:

$$\eta = 95.76209 [T_L \mu g/\rho^2 N^5 D_b^8]^{-0.05003} [M_{ang}]^{-0.04363} [D_{ho} D_{hi} L_h F_o F_t l_b l_t/D_b^8]^{-0.05502} [l_n]^{-0.03421} [Nt_0]^{0.00881}$$

The absolute indices of the various pi-terms $[T_L \mu g/\rho^2 N^5 D_b^8]$, $[M_{ang}]$, $[D_{ho} D_{hi} L_h F_o F_t l_b l_t/D_b^8]$ & $[l_n]$ are negative shows that the Torque Transmission Efficiency varies inversely with the load torque, angular misalignment, geometrical parameters of the coupling, and number of lobes respectively. The positive index of the pi-term $[Nt_0]$ shows the direct variation of Torque Transmission Efficiency with speed & operational time. . The curve fitting constant being greater than one shows the effect of some additional response variables which might not be considered in the phenomenon.

The model for the Fourth response variable i.e Rise in temperature of Lubricant (Pi 04) is:

$$\Delta\theta/\theta_a = 0.00059 [T_L \mu g/\rho^2 N^5 D_b^8]^{0.00436} [M_{ang}]^{0.34344} [D_{ho} D_{hi} L_h F_o F_t l_b l_t/D_b^8]^{-0.02611} [l_n]^{-0.04225} [Nt_0]^{0.49523}$$

The absolute index of the pi term $[Nt_0]$ is positive & higher shows the direct variation of Temperature Rise with the speed & operational time. The absolute indices of the pi-terms $[T_L \mu g/\rho^2 N^5 D_b^8]$, & $[M_{ang}]$ are moderate shows the moderate effect of load torque & angular misalignment on Temperature Rise of lubricant, The absolute indices of the various pi-terms $[D_{ho} D_{hi} L_h F_o F_t l_b l_t/D_b^8]$, $[l_n]$,& $[Nt_0]$ are negative shows that Rise of Temperature of lubricant varies inversely with geometrical parameters of the coupling and lobes, number of lobes and speed respectively.

V. CONCLUSION

- 1) A new type of ball joint lobe coupling has developed which offers improved compensation for angular misalignment.
- 2) Experimental data based model is formulated and comparison of the same model is made with mathematical model as well as

ANN model. The response data generated by ANN model found to be similar to the one developed by the experimental data based model. This gives the authenticity to the responses predicted.

3) The response variables like Input power, Driving torque varies greatly with load torque, varies moderately with speed, geometrical parameters of the coupling and lobes and less affected by angular misalignment and number of lobes.

4) Torque transmission efficiency of the coupling varies inversely with load torque but varies directly with the speed of the coupling shaft.

5) The temperature rise of lubricant varies directly with operational time and speed of the coupling shaft.

6) The models developed truly represent the degree of interaction of various independent variables. This is only made possible by the approach adopted in this investigation.

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