Formulation of Empirical Relationship for the Analysis of Dynamics of Spherical Joint-Lobe Coupling

Dr. Vinod Bhaiswar[1], Mr. N. N. Bhaiswar[2]

[1] Associate Professor of Mechanical Engineering, GHRaisoni College of Engineering, Nagpur

[2] Assistant Professor, Priyadarshini Indira Gandhi College of Engineering, Nagpur.

Abstract

This research work presents an establishment of dynamic characteristics of newly developed spherical joint lobe type flexible coupling through extensive experimentation. The phenomenon of kinetic energy transmission from one shaft to other shaft through this spherical joint flexible coupling is so complicated that the logic based modelling is highly improbable to be developed. Hence, it is decided to formulate the generalized experimental data based model which can be used as a design data. This research work is helpful in the design of coupling of modern combine to allow running shaft misalignment.
Since the phenomenon of dynamics of coupling is complicated and is having high non linearity, artificial neural network simulation has been formulated for experimental data obtained during experimentation.
The behaviour of real phenomenon or model is evaluated qualitatively and quantitatively.
Keywords: Spherical Joint-flexible Coupling, modern combine, Angular Misalignment

1. INTRODUCTION

Coupling is one of the responsible components in transmission system which connects the rotating shafts together. Since it is nearly impossible to maintain perfectly collinear centerlines of rotation between two or more shafts, flexible couplings are designed to provide a certain degree of yielding to allow running shaft misalignment. This is especially true in today’s industrial environment, where system designers are demanding higher speeds, higher torque, greater flexibility, additional misalignment for flexible couplings. As the technology advances, the need for flexible coupling is becoming more and more acute. Several flexible coupling designs emerged immediately after the introduction of the automobile. As shaft speed increased, coupling designs were continually refined to accept the new demands placed on them. As industrial competition became more severe, equipment downtime became a major concern and industry became increasingly more interested in coupling failures in an effort to prolong operating lifespan. As per the industrial demand of higher speeds, higher torque and higher angular misalignment, a, coupling designs are continually refined with the ultimate goal of designing the ‘perfect’ coupling.

2. RECENT DEVELOPMENT IN THE FIELD OF DYNAMICS OF COUPLING.

Kargin, P.A. [1] presents the results of limited performance of a Russian make modern combine due to short life of a compensatory gear coupling in transmission system of the machine. The responsible element was toothed coupling. The problem arose of how to provide a maximum service life of the coupling. One of the possible ways of improving the service life of a gear coupling is the implementation of production engineering measures which ensures a better accuracy in the manufacture of the parts and in the assembly of the units of a combine and the demanded reduction in the misalignment of the shafts, but the results have shown the economical inexpediency of such a course under mass production conditions. A second way which entails a widening of the compensatory capabilities of the coupling was found to be unacceptable for this particular gear coupling because any additional reduction of the thickness of the teeth would have meant a substantial lowering of their strength and would have worsened the stability of the rotation of the countershaft.
Xu, Ming & Marangoni, R.D. [2] lays emphasis on the effects of unbalance on coupling running under misalignment condition. The paper describes the theoretical model and analysis.
McCormick, D. [3] proposes various factors for specifying a right flexible coupling for rotating equipment drive system. Some of the important factors are normal horsepower and speed, maximum horsepower/torque being transmitted at maximum speed, misalignment capacity; parallel, angular, and combination of both parallel and angular,

torsional flexibility, type and amount of lubricant, how is the coupling attached to the shafts, installation procedure, heat generated from misalignment, type of environment coupling will be exposed to.

Nower, Daniel [4] describes about the various kinds of misalignments; parallel offset, angular, and combined angular and offset. The paper lays emphasis on the reliability of the coupling.

3. Background Of The Present Research.

Modern combine is one of the most important machines in mechanized agriculture as the mechanization of grain harvesting has been a long time objectives of farmers. The mechanisms included in a combine accomplish five general functions, viz. cutting, feeding, threshing, separating and cleaning. It has been adapted to the harvest of more than 100 food, feed, and processing grain crops. Because of ground topology in agriculture field, high angular misalignment occurs in coupling shafts of the combine which reduces the service life of the coupling. After gone through detailed literature review, it is observed that none of the coupling is having the capacity to accept such high level of angular misalignment .So an idea of new type of coupling is conceived in this investigation which can accept high angular misalignment in the shafts and also helps to prolong the operating life span of the modern combine.

4. Scope And Objectives Of Present Investigation

In present research, it is proposed to develop a new type of spherical joint-lobe coupling to accept required range of angular misalignment and formation of design data required for various specifications of modern combine harvester.

Formation of design data will be in form of generalized experimental data based models for various output parameters of the coupling. These output parameters are driving power, input torque, power transmission efficiency and increase of lubricant temperature.

5. Experimental Approach

The experimental approach suggested by H. Schanck Jr. [5] is helpful in planning and execution of experimentation and obtaining reliable conclusions from experimental data. It involves (i) Selection of input and output variables(ii) Reduction of variables using dimensional analysis technique.(iii)Formation of mathematical relationship between independent and dependent pi terms(iii)Planning for test sequence either using classical plan or factorial plan (iv)Design of an experimental setup. (v) Fabrication of an experimental setup (vi)Selection of instrumentation for experimental setup(vii) Execution of experimentation as per planning (viii)Test data checking and rejection(ix)Formulation of model based on purified experimental data.

Table 1: Variousinput and output variables of the coupling

Input Variables				
Sr. No.	Parameter	Symbol	Units	Dimension
1	Speed	N	Rps	$M^0L^0T^{-1}$
2	Load Torque	T_L	N-m	$M^1L^2T^{-2}$
3	Angular Misalignment	M_{ang}	rad	$M^0L^0T^0$
4	Outside Diameter of Hub	D_{ho}	m	$M^0L^1T^0$
5	Inside Diameter of Hub	D_{hi}	m	$M^0L^1T^0$
6	Outside Diameter of Flange	F_o	m	$M^0L^1T^0$
7	Thickness of Flange	F_t	m	$M^0L^1T^0$
8	Length of Hub	L_h	m	$M^0L^1T^0$
9	No of Lobes	l_n	m	$M^0L^0T^0$
10	Length of Lobe	L_l	m	$M^0L^1T^0$
11	Breadth of Lobe	l_b	m	$M^0L^1T^0$
12	Thickness of Lobe	L_t	m	$M^0L^1T^0$
13	Ball Diameter	D_b	m	$M^0L^1T^0$
14	Viscosity of Lubricant	M	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_i	^{0}C	$M^0L^0T^0\theta^1$
Output Variables				
1	Driving Power	P_{in}	watts	$M^1L^2T^{-3}$

2	Input Torque	T_d	N-m	$M^1L^2T^{-2}$
3	Power Transmission Efficiency	η	---	$M^0L^0T^0$
4	Increase of lubricant temperature	$\Delta\theta$	^0C	$M^0L^0T^0\theta^1$

6. Experimental Procedure

The procedure of performance of the test as per the experimental plan and measurement of important parameters are given below:

6.1 Procedure of Execution of Experimentation

By using a classical plan, the experimentation is performed at four different levels of speed. Initially, the motor was allowed to run and shaft speed is maintained at the first level with the help of gear box. As per the experimental plan, the load torque is varied over its range keeping other values of pi terms at its mean level. During each trial, the initial and final temperature of the lubricant was recorded and lubricant is changed with fresh one for next trial. For the next set of readings, the earlier independent pi term is fixed at their mean value and one of the other independent pi terms is varied over its range. In similar way, the experimentation is performed for four different levels of speed. During each trial, the measurements of all important parameters are recorded.

FIG.-1 Setup of Spherical Joint-lobe type flexible coupling

6.2 Measurement of important Parameters

a) Driving Power
b) Input Torque
c) Power Transmission Efficiency
d) Increase of Lubricant Temperature

7. Development Of Generalized Experimental Data Based Model

The model formulation has been done in two ways:

7.1 Generalized experimental data based mathematical modelfor response variables are as follows:

For Driving Power:

Pi 01 = 251.01 * π10.48197 π20.03766 π30.0565 π40.03944 π50.09727

Pin/ρN2Db5=251.01[TLµg/ρ2N5Db8]0.48197[Mang]0.03766[DhoDhiLhFoFtlllblt/Db8]0.05659[ln]0.03944[Nt0]0.097

For Input Torque:

Pi 02 = 39.88 * π10.482 π20.038 π30.057 π40.039 π50.097

Td/ρN2Db5=39.88[TLµg/ρ2N5Db8]0.482[Mang]0.038[DhoDhiLhFoFtlllblt/Db8]0.057[ln]0.039[Nt0]0.097

For Power Transmission Efficiency:

Pi 03 = 95.76 * π1-0.05003 π20.03766 π3-0.05502 π4-0.03421 π50.00881

η=95.76 [TLμg/ρ2N5Db8]-0.05003[Mang]-0.04363[DhoDhiLhFoFtlllblt/Db8]-0.05502[ln]-0.03421[Nt0]0.00881

For Increase of Lubricant Temperature:

Pi 04 = 0.01 * π1-0.00436 π20.34344 π3-0.02611 π4-0.04225 π50.49523

Δθ/θa=0.01[TLμg/ρ2N5Db8]0.00436[Mang]0.34344[DhoDhiLhFoFtlllblt/Db8]-0.02611[ln]-0.04225[Nt0]0.49523

7.2 Artificial Neural Network (ANN) Simulation

ANN simulation is a combination of artificial intelligence and network of neurons (neural).It is nothing but a computational model developed because of complex phenomenon.

8. Results And Discussions

The experimental data of this new type of coupling i.e. spherical joint-lobe type flexible coupling has been collected through experimentation. The observations are recorded as per the experimental plan. The experimental data obtained has been converted into interpretable form and analysed to draw some logical results for useful discussions. Initially qualitative analysis of the data has been done to evaluate the behaviour of model through presentation (as shown in figure 2, 3, 4&5) and then quantitative analysis of the data in order to quantify or evaluate the behaviour of real phenomenon using experimental data based modeling (Equation-1,2,3&4).

8.1 Qualitative analysis of the data for response variables

In the phenomenon of spherical joint lobe type flexible coupling, there are four dependent pi terms related to response or output variables viz. Driving Power, Input Torque, Power Transmission Efficiency& Increase of Lubricant Temperature.

Figure 2 to 5 shows the comparison of graphs amongst the product (pi1*pi2*pi3*pi4*pi5) verses experimental data based values, mathematical model values and ANN model values of pi1, pi2, pi3&pi4 respectively.

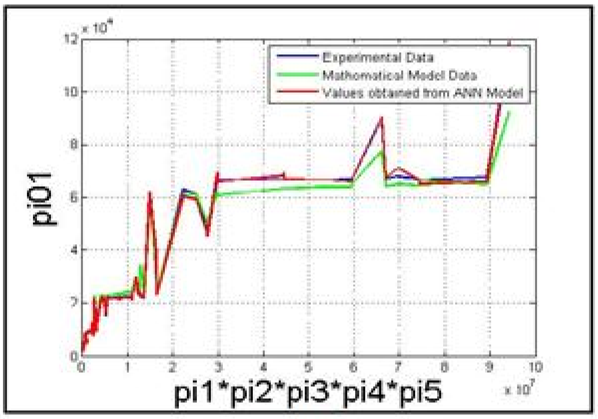

FIG-2

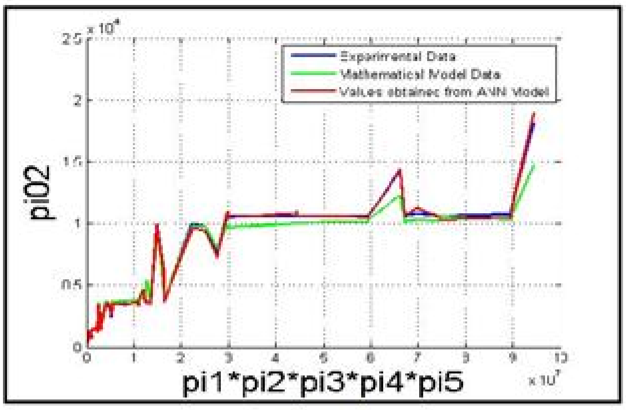

FIG-3

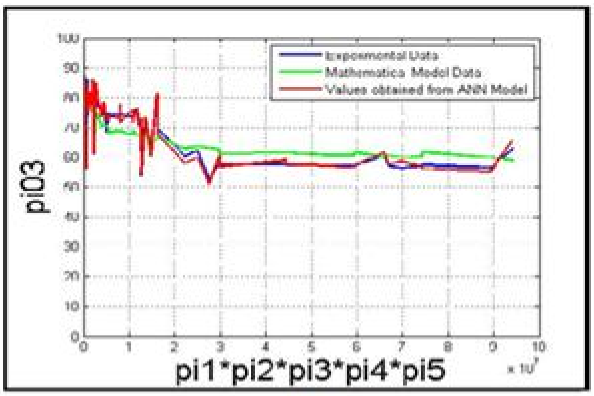

FIG.-4

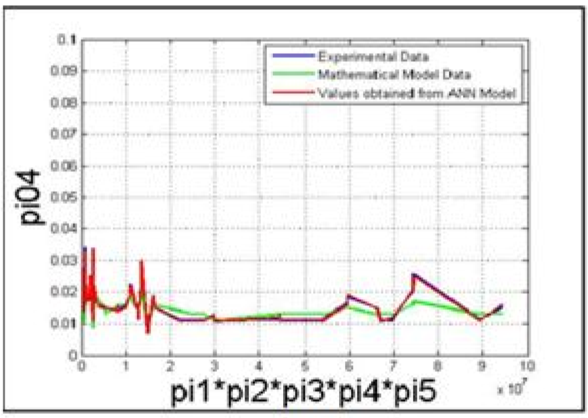

FIG.-5

From the comparison of above graphs(Figure-1 to5), it is observed that the curves of responses(output variables in pi terms)obtained are overlapping due to less percentage error and gives us an accurate relationship between experimental data, data obtained through mathematical model based on regression analysis, and the data generated through ANN simulation. This gives the authenticity to the responses predicted. Thus, qualitatively it is observed that the phenomenon is complex.

8.2 Quantitative analysis of the data for response variables

The quantitative analysis of model of response variables viz. Driving Power, Input Torque, Power Transmission Efficiency& Increase of Lubricant Temperature are given below as Equation-1 to Equation-4.The formation of these models are based on multiple regression analysis.

The model for the First response variable i.e. Driving power (Pi01) is:
Pin/ρN2Db5=251.01 [TLμg/ρ2N5Db8]0.48197[Mang]0.03766[DhoDhiLhFoFtlllblt/Db8]0.05659[ln]0.03944[Nt0]0.09727
Or Pi 01 = 251.01 *π10.48197 π20.03766 π30.0.0565 π40.03944 π50.09727 (1)

The model for the Second response variable i.e.Input torque (Pi 02) is:
Td/ρN2Db5=39.88 [TLμg/ρ2N5Db8]0.482[Mang]0.038[DhoDhiLhFoFtlllblt/Db8]0.057[ln]0.039[Nt0]0.097
Or Pi 02 = 39.88 * π10.482 π20.038 π30.057 π40.039 π50.097 (2)

The model for the Third response variable i.e. Power Transmission Efficiency (Pi 03) is:
η=95.76 [TLμg/ρ2N5Db8]-0.05003[Mang]-0.04363[DhoDhiLhFoFtlllblt/Db8]-0.05502[ln]-0.03421[Nt0]0.00881
Or Pi 03 = 95.76 * π1-0.05003 π20.03766 π3-0.05502 π4-0.03421 π50.00881 (3)

The model for Fourth response variable i.e. Increase of lubricant temperature(Pi04)is:
Δθ/θa=0.01 [TLμg/ρ2N5Db8]0.00436[Mang]0.34344[DhoDhiLhFoFtlllblt/Db8]-0.02611[ln]-0.04225[Nt0]0.49523
Or Pi 04 = 0.01 * π1-0.00436 π20.34344 π3-0.02611 π4-0.04225 π50.49523 (4)

The value of exponents of these models gives the indication of how the system behaviour is changingwith the changes of input pi terms in the generalized mathematical models. The constant values in the equation-1, 2, 3 & 4 are 251.01, 39.88, 0.01, & 95.76 respectively called curve fitting constant of the models.These values represent collectively the influence of extraneous variables on the responses.

9. CONCLUSION

1. An idea of spherical joint lobe type flexible coupling is conceived in this investigation. This new type of coupling is ascertained to have some special features as proved through this investigation.
2. Performance evaluation of this new type of coupling is made possible through established experimental data based model.
3. It is found through investigation that Power transmission efficiency of the coupling is directly proportional to speed of the coupling shaft and inversely proportional to load torque.
4. The output variables like driving power, input torque are directly proportional to load torque.
5. The design of new spherical joint-lobe coupling is intended to join shafts with a misalignment up to 30degrees.
6. The established models through this investigation are design data itself.

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AUTHORS

Dr. Vinod Bhaiswar, Associate Professor in Mechanical Engineering Department at G .H .Raisoni College of Engineering, Nagpur.
Academic Profile: Ph. D. (Mechanical Engineering), R. T. M. Nagpur University, Nagpur, M. Tech. (Mechanisms & Machine Design), V. R. C. E. Nagpur, B. E. (Mechanical Engineering), R. T. M. Nagpur University, Nagpur.
Research Grants/Patents: Research grant obtained for the project titled, "Design & Fabrication of a spherical Joint Lobe Coupling" under Research Promotion Scheme (RPS) of AICTE. Two patents filed titled "Reverse Tricycle with steering mounted controls & reclining seat"& "Sugarcane cutting Machine". Involvement in Sponsored Research Project titled "Vibration Based Condition Monitoring of Drag Line" of WCL, Nagpur from 2002 to 2008.Involvement in Consultancy Assignments on "Design and Development of Automatic Plant for Manufacture of Fly-Ash Bricks" of Vasant Chemicals, Hyderabad in the year 2003.
Membership of Reputed Professional Bodies :Life Member, Indian Society for Technical Education, New Delhi, Life Member, Indian Society of Heating, Refrigerating & Air Conditioning Engineers., Life Member, Indian Society of Biomechanics. Publications: International Journal-18, International Conference-08, National Conference-06

Naresh Bhaiswar, Assistant Professor in Mechanical Engineering at Priyadarshini Indira Gandhi College of Engineering, Nagpur.
Academic Profile: M. Tech. (Mechanical Engineering Design), P. C. E. Nagpur, B. E. (Mechanical Engineering), S.G.B. Amaravati University, Amaravati.
Membership of Reputed Professional Bodies : Life Member, Indian Society for Technical Education, New Delhi, Life Member, International Association of Academicians and Researchers, Life Member of International Association of Engineers. Publications: International Journal-09, International Conference-02, National Conference-02