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Design and Development of Load Pin for Measuring Pin Joint Reaction of Wheel Loading Shovel Machine

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Abstract—*This paper focuses on investigation of probability distribution of input forces of in-deterministic model through an electromechanical system by using load pins to understand the dynamic behavior of Wheel Loading Shovel machine. Load pin senses the force applied across it by using strain gauges installed within a small bore through the center of pin which is used to convert an electrical signal to mechanical signal. Work started with concept design of load pin that is based on considering reaction acting on pin to determine the plane on which strain gauges are supposed to be mounted. Four strain gauges connected to form full bridge Wheatstone circuit in response to load from bucket. As pure shear is to be measured, plane of strain gauges has to be normal to reaction at pin. Afterwards FEA of system is carried out and reactions are used to validate the theoretical results.*
In FEA virtual strain gauges are inserted on pin with plane of gauges normal to reaction on pin. This plane of strain gauges gives maximum shear strain and is more sensitive to measure shear strain in field. Thus with FEA results, this design can be suggested for calibration of load pin and can be used for field tests such as material handling test and some field tests.

1. INTRODUCTION

Wheel Loading Shovel machine is a heavy equipment machine used in Mining and Construction work such as recycled material, rock, raw minerals, gravel, sand etc. In order to understand the dynamic behavior of construction equipment machines in test fields, it is very important to understand pivot reactions. To get the transmission of load through structure it is necessary to get reactions at pivots. So, reactions at pivots can be measured by using load pins in place of actual pins which will give the life of pivots.

Initially single pin between bucket and loader arm is selected for concept prove. This pin is to be replaced with load pin to understand the reactions acting at pivot. A load pin is a transducer that is used to create an electrical signal and convert it into mechanical signal using data acquisition system whose magnitude is directly proportional to the force being measured. Initially force acting on pin is taken into consideration to get the plane of insertion of shear strain gauges. To measure pure shear strain, plane of insertion of stain gauge has to be normal to force acting on plane. Thus shear stain gauges are pasted over the slots that are normal to reaction on pin and thereafter connected to data acquisition system.

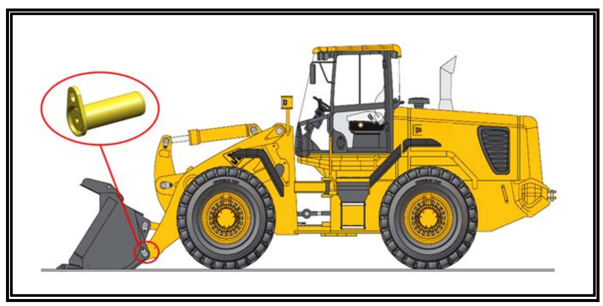

Fig. 1: Wheel loading shovel

James Brandon Allen [1], "Estimating Uncertainties in the Joint Reaction Forces of Construction Machinery" In this thesis, mechanism is modeled in MATLAB by using differential algebraic equations and compared with CAD model in Pro-Mechanica. Collocation method was developed for comparison of MATLAB and Pro-Mechanica models. Thus difference between two results gives uncertainties in joint reaction forces.

A. F. Kheiralla et al. [2],"Design and Development and Calibration of an On-board Weighing System for an Industrial Wheel Loader". Load pins are design, developed and calibrated for an onboard weighing system of an industrial wheel loader to provide on the go weighing for trucks. Three locally made load pins replaced existing pins for developing on board weighing system for Wheel Loader.

Jahmy Hindman [3], "Stochastic Modeling of a Four Wheel Drive Loader Linkage" In this paper effect of manufacturing tolerance to Industrial Wheel Loader is taken into consideration for understanding extent of these tolerances on linkage position for standard machining tolerances of each linkage pin joint for a four wheel drive loader linkage. It was then proved that effect of machining tolerance on this linkage have minor impact on linkage position.

2. WORK STATEMENT

Measuring joint reaction forces that occur in pivot pins in field testing.

3. RESEARCH OBJECTIVE

-Concept design & development of load pin for measuring joint reaction forces.

-Validate the load pin concept design using FEA.

4. RESEARCH WORK

Initially static force analysis of the Wheel Loader mechanism is done to understand the reactions acting on pivots. Knowing reaction at pin between bucket and loader arm, conceptual design of load pin started. And finally validation of conceptual design through FEA results is done.

5. CONCEPTUAL DESIGN OF LOAD PIN

To measure shear strain, four slots are constructed in CAD geometry along shear plane and two through slots are made to pass wire connecting strain gauges to data acquisition system.

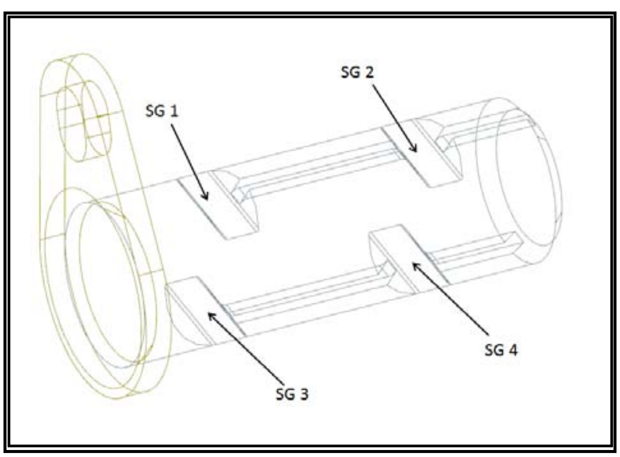

Fig. 2: Location of strain gauges

As shown in Fig. 2, four strain gauges SG 1-2-3-4 are located on the periphery of the pin.

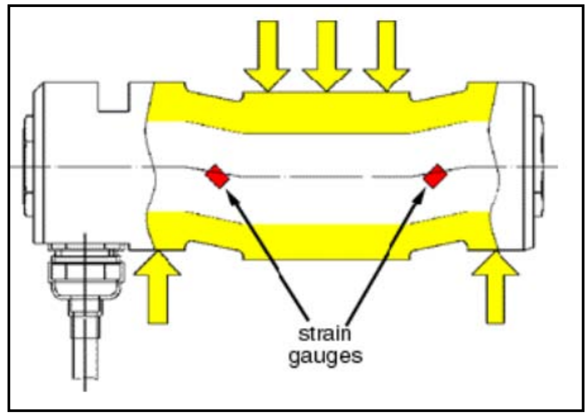

Fig. 3: Load pin with strain gauges

As shown in Fig. 3, FBD of load pin can be considered. Vertical loading is done on upper face and lower faces are fixed. Strain gauges are arranged to form full bridge Wheatstone circuit and are located normal to vertical loading plane.

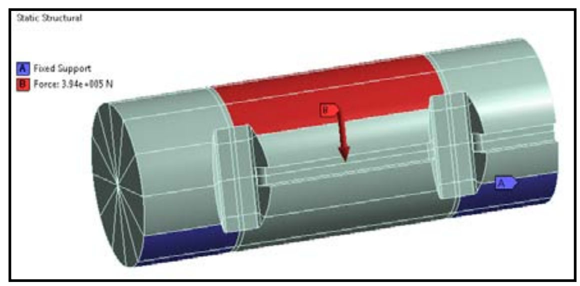

Fig. 4: Load case of load pin

Same concept is used as shown in Fig. 4. It consists of vertical loading on upper face and lower faces are fixed. Slots are made to insert strain gauges.

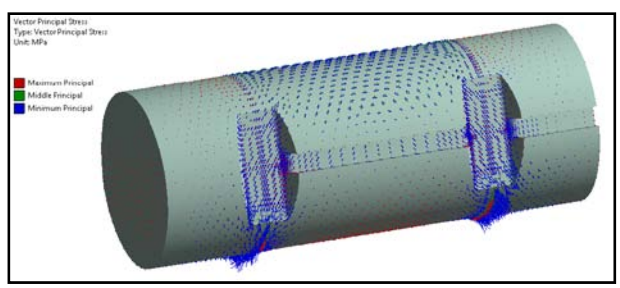

Fig. 5: Vector principle stress

From above Fig. 5, it is clear that pure shearing action takes place at selected plane of virtual strain gauges. Considering above load case, same terminology can be used in FEA of Wheel Loader assembly.

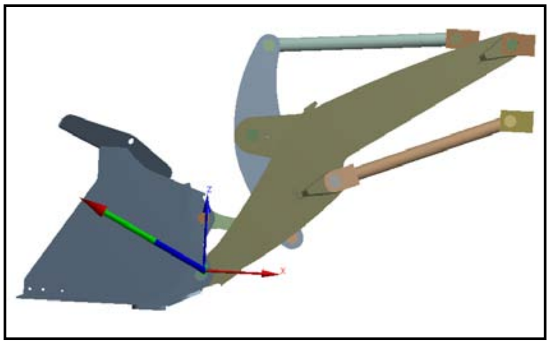

Fig. 6: Reaction on pin

From Fig. 6, Reaction acting on pin is 337 KN. To measure pure shear, Plane of shear strain gauges has to be normal to reaction acting on pin. As shown in above Fig. 6, reaction acting on pin is at an angle of 150 degree, so strain gauges must be mounted on normal reaction plane.

6. MATERIAL PROPERTIES AND MATHEMATICAL MODELING OF LOAD PINS

Pin diameter: 90 mm
Pin length: 255 mm
Material: EN10083 (42CrMo4)

Table 1: Mechanical composition

Parameter	Value
Carbon	0.38%-0.45%
Manganese	0.6%-0.9%
Silicon	0.4%
Phosphorus	0.035%
Sulphur	0.035%
Ultimate Tensile Strength (N/mm2)	1100
Yield Strength (N/mm2)	980
Elongation	10-15%

Maximum Shear Stress:

$$\tau = \text{Ksb} * \frac{2 * \text{F}}{\pi * D^2}$$

$$\tau = 1.5 * \frac{2 * 337 * 10^3}{\pi * 90^2}$$

$$\tau = 39.729$$

Where K_{sb} is service factor for bending
Maximum shear stress induced is 39.729 MPa.
Modulus of rigidity of steel is 79.2 GPa.

$$\text{Shear strain} = \frac{\text{Maximum Shear Stress}}{\text{Modulus of rigidity}}$$

$$\gamma = \frac{39.729}{79.2 * 10^3}$$

$$\gamma = 501.63$$

Thus maximum shear strain induced is 501.63 micro-strains.

7. VIRTUAL STRAIN GAUGE RESULTS THROUGH FEA

(Assumption: In FEA heat treatment effect of pin is not considered)

Load case of Wheel Loading Shovel machine as shown in Fig. 6, is taken for measuring virtual strain results on load pin. Coordinate system is defined to insert virtual strain gauges over the pin as shown in figure7, Virtual strain gauges are the strain gauges inserted on the CAD model of the part to get the value of strain along X, Y, Z axis. Once coordinate system is defined contacts are defined. In this model frictional contact is defined between pins, bucket and loader arm with frictional contact between metal to metal as 0.2. After this meshing is done; in meshing local contact area where fine mesh is required is body sized and other parts are poor meshed. Element type used for meshing is 10 nodes tetrahedral. Virtual strain gauge results are checked for two different planes of strain gauges i.e. 60 degree plane and 70 degree plane. Virtual strain gauge values measured in 70 degree plane are more sensitive as compared to 60 degree plane, so pin with strain gauges at 70 degree are drafted for fabrication purpose.

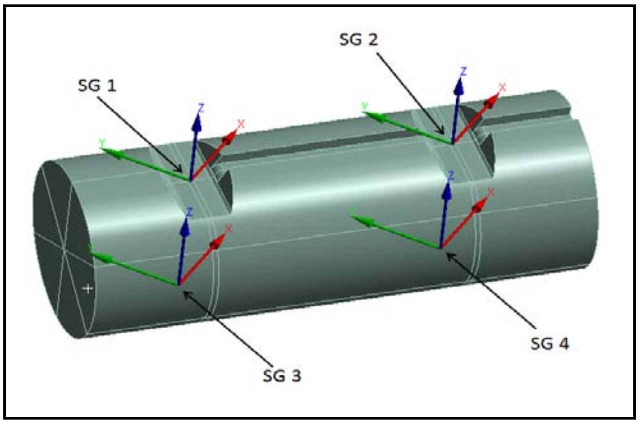

Fig. 7: Installation of strain gauges on pin

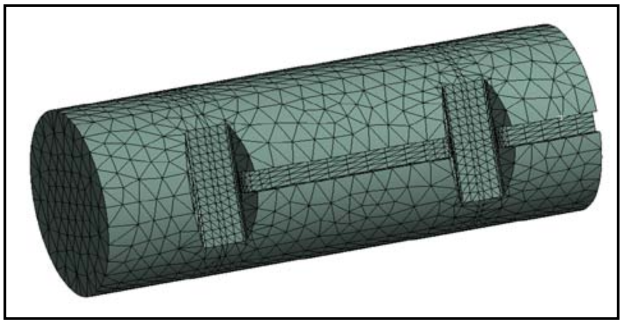

Fig. 8: Meshed model

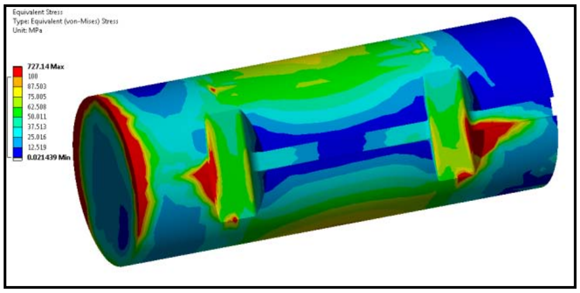

Fig. 9: Von-Mises stresses

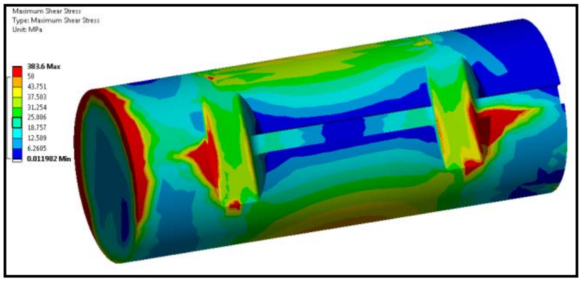

Fig. 10: Maximum shear stress

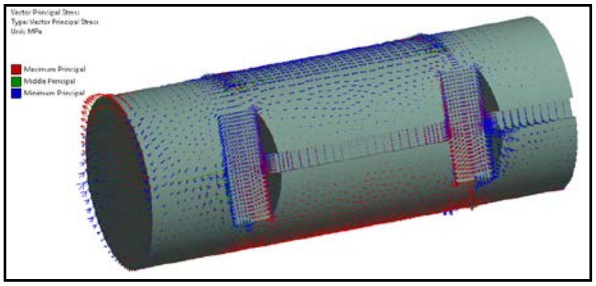

Fig. 11: Vector principle stress

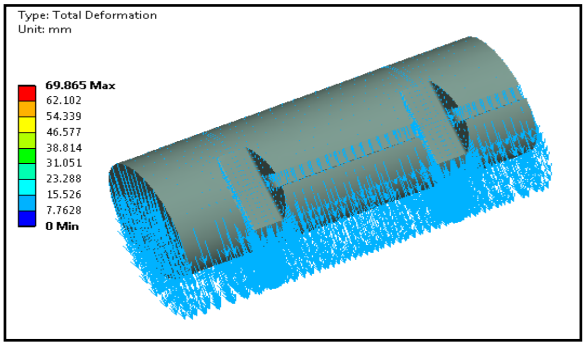

Fig. 12: Total Deformation

Plane normal to reaction on pin comes out between 60 -70 degree, so results are taken for two different load cases; in first load case virtual strain gauges are inserted on 70 degree plane and in second load case strain gauges are mounted on 60 degree plane.

Table 2: Virtual strain results

Shear Strain		Strain gauge at 70 deg		Strain gauge at 60 deg	
		Breakout	Combined	Breakout	Combined
SG1	along_X	58.414	72.387	55.763	61.395
	along_Y	40.66	22.23	14.339	-4.3428
SG2	along_X	-57.302	-92.552	-84.824	-123.17
	along_Y	142.14	176.85	136.34	162.53
SG3	along_X	235.72	353.91	244.7	363.28
	along_Y	-371.96	-494.7	-352.63	-464.95
SG4	along_X	-277.11	-378.15	-261.34	-349.07
	along_Y	136.16	222.58	151.02	238.11

In breakout load case uniformly distributed load is applied at shovel and in combined load case both breakout and tractive forces are applied.

Virtual strain values are inserted along X and Y axis for breakout and combined load case. Maximum shear strain among two is of 70 degree plane, so this plane is more sensitive for actual test results. As shown in table 2, Maximum strain obtained among two load case is 494 microstrain.

8. CONCLUSION

Shear strain obtained using mathematical modeling and virtual strain gauges in FEA are almost same. Thus conceptual design of load pin is validated theoretically and analytically. Load pin design approach can be taken for next level of testing that is manufacturing load pins and acquire shear strain in field and to get machine dynamic factor.

9. ACKNOWLEDGEMENTS

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