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Static and Dynamic Analysis of Epicyclic Gear Train

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Abstract: *Planetary Gear Trains Are Generally Used For Automatic Transmission, Overdrives, And Final Drives. Most Occurred Problems In Using The Gearbox Is The General Gear Failure Problem Due To The Wear And Tear Of The Gears While Rotating And The Vibrations Produced While Transmission. This Problem Occurs In Most Gearboxes But In Case Of The Planetary Gearbox These Problem Can't Be Found Out Before Failure Due To The Complex Shape Of Planetary Gearbox. In The Static And Load Sharing Analysis Of Planetary Gear System, First Stresses And Percentage Load Sharing Are Calculated Theoretically And Then These Analytical Results Are Validated By Finite Element Analysis Of Gearbox Setup Experimental Results Of Planetary Gearbox At Static Conditions. The Load Sharing Of The Planet Pins Cannot Be Found Out By Experimentally Directly. The Project Work Has The Dynamic Analysis Of Rim Of The Ring Gear Of Planetary Gearbox. In Dynamic Analysis, Simulation Results Are Validated By Experimentation. From The Valid Simulated Results Dynamic Load Sharing Is Found. DEWE-43 DAQ System Is Used For Dynamic Experimentation And For Static Measurements DEWE-43 DAQ And Panopticnode J-Logger Is Used. In Static Simulation, CATIA V5R21 For Modeling And ANSYS Workbench Finite Element Analysis Is Used. In Dynamic Analysis The Model Is Meshed In HYPERMESH And To Solve The Simulation Problem LS-Dyna Software Is Used.*

Keywords: *Dynamic Analysis, DEWE-43, Epicyclic Gear Train, Panopticnode J-Logger, Load Sharing*

I. Introduction

The Planetary Gear Box Known As Epicyclic Gear Box Possess Many Characteristics That Make Them To Use In Place Of Parallel-Axis Drives. Planetary Gear Systems Are Complex, Multi-Mesh Systems. Planet Gears That Are In Mesh With A Sun Gear And A Ring Gear And Are Connected By A Carrier Through Pins. Planetary Gears Are Typically Classified As Simple And Compound Planetary Gears. Simple Planetary Gears Have One Sun, One Ring, One Carrier, And One Planet Set. Compound Planetary Gears Involve One Or More Of The Following Three Types Of Structures: Meshed-Planet (At Least Two More Planets In Mesh With Each Other In Each Planet Train), Stepped-Planet (There Exists A Shaft Connection Between Two Planets In Each Planet Train), And Multi-Stage Structures (The System Contains Two Or More Planet Sets). Compared To Simple Planetary Gears, Compound Planetary Gears Have The Advantages Of Larger Reduction Ratio, Higher Torque-To-Weight Ratio, And More flexible Configurations. That Is Why Planetary Gear Systems Widely Used In The Industry, National Defense And Aerospace.

It Is Proved That Equal Sharing Of The Input Torque Between The Planet Gears Of The Planetary Gear Train Assembly Is Not Possible Practically, Because Of Existence Of Manufacturing Errors, And Assembly Variations. The Objective Of This Study Is To Measure Load Sharing Between Planet Gears For Static And Dynamic Conditions. There Are Strain Gauges Mounted On The Planet Pins For Instantaneous Measurement Of Planet Loads Regardless Of Whether The Errors Are Constant Or Time-Varying.

In Dynamic Analysis Stresses Developed In The Rim Of The Ring Gear Are Simulated By Using HYPERMESH And LS-Dyna Solver And These Results Are Validated Experimentally. For Experimentation Strain Gauges Are Placed On The Rim Of Ring Gear And DEWE-43 DAQ System And Panopticnode J-Logger Are Used For The Measuring And Data Logging Purpose. Form Valid Simulated Results Load Sharing Is Calculated.

The Main Objective Of The Project Work Is To Find An Effective Way For The Measuring Of Load Sharing Of The Planet Pins Of The Planetary Gear Box In Static As Well As Dynamic Conditions.

Experimental Setup

Planetary Gear Box Contains Sun Gear, Ring Gear And Three Planet Gears In 120° Angle To Each Other. In This Gear Box, Input Is Given To The Sun Gear And Output Is Given To The Carrier. The 3 HP Motor Having Maximum 3000 Rpm Is Attached To The Planetary Gear Box Step With A Flexible Coupling In Between Output Shaft Of Motor And Input Shaft Of Planetary Gear Box. Brake Drum Dynamometer Is Attached On The Output Shaft Of Planetary Gear Box And Two S Type Load Cells Are Used To Measure Force With A Two Decimal Accuracy. In This One Load Cell Is Fixed To The Frame And Other Is Attached To The

Screw For Applying Tensile Force On It. The Whole Setup Is Placed Upon The Concrete Foundation By Bolting It To The Foundation To Give Rigidity And Necessary Damping For The Vibration Produced By The Gear Box. This Setup Is Prepared For Dynamic Load Conditions And Static Load Condition.

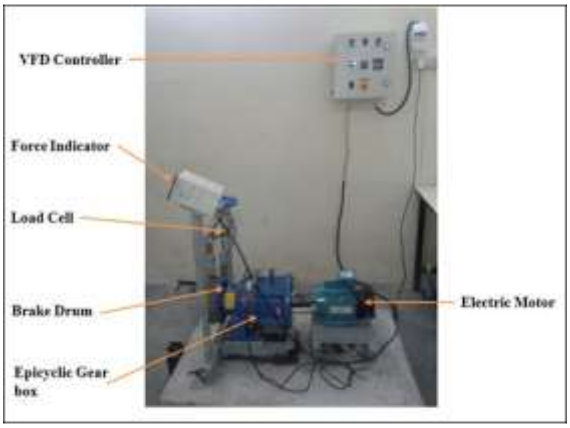

Fig. 1 Experimental Setup Of Planetary Gear Set

Static Analysis And Load Sharing

In This Chapter Static Load Sharing Capacity Of Planetary Gear Is Explained. If There Are X Number Of Planets In The Planetary Gear Set, Ideally Each Planet Gear Is Carries An Equal Amount Of Torque, So Generally They Are Designed To Carry 1/X Amount Of The Input Torque.

In This Chapter Theoretical Stresses Calculated Are Compared With Experimental Stresses Measured By J-Logger And DEWE-43 DAQ. Then Theoretical Stresses Are Compared With The Stresses Calculated By Simulation Of Planetary Gear Set In ANSYS Workbench.

For Measuring The Load Sharing Strain Gauges Are Pasted On The Arm Pins Mounted On Each Of The Planet Gears, Which Is Only Useful For The Static Measurements.

Fig. 2 Strain Gauge Location And Loading Setup For Static Measurement

For Taking Measurements Mainly Two Types Of The Daqs Are Used, One Is DEWE-43 DAQ System And Other One Is Panopticnode J-Logger. The Second One Is Unable To Give The Exact Stress Values Measured Due To The Variation Of Resistance Comes In Each Strain Gauge Channel. On The Other Hand DEWE-43 DAQ Gives The Exact Value Of Strains Measured.

Theoretical Stress

The Theoretical Stresses Are Calculated By Considering Pin As A Cantilever Beam On Which The Forces Are Exerted As Shown In Free Body Diagram Of The Planetary Gear Set In Fig. 4. Then The Load Sharing Is Given By Equation 1.

$$Load\ sharing\ by\ particular\ planet = \frac{\sigma_n}{\sum \sigma_n}$$

Where, $\sigma_n = Stress\ in\ individual\ pin$

$\sum \sigma_n = summation\ of\ stresses\ in\ all\ pins$

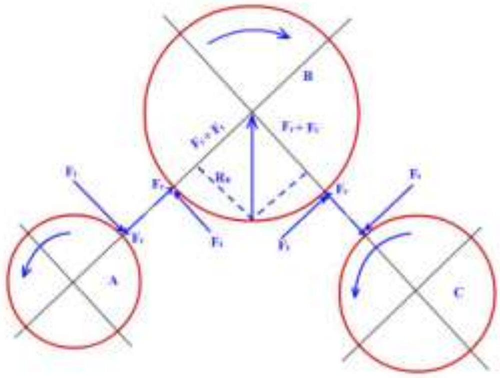

Fig. 3 Free Body Diagram Of Planetary Gear Set

Strain Measurements By Daqs

As There Are Two DAQ Systems Are Used For The Measurement For The Static Condition.

Panopticnode J-Logger

First Of All Strain Gauge Wires From Arm Pins Of The Respective Planet Gear Set Are Connected To A Wheatstone Bridge In Quarter Bridge Mode. Then Each Channel From Strain Gauge Is Connected To The DAQ Which Is Connected To The Logger.

Fig. 4 Panopticnode J-Logger And DEWE 43 Setup

DEWE-43 DAQ

This Is A Data Acquisition System From DEWESOFT Ltd. For Measuring Strain Using This DAQ First Of All Strain Gauge Wires Are Connected In The Quarter Bridge Circuit Mode. Then Each Strain Gauge Channel Is Connected To The DAQ Which Has Inbuilt Logger.

Load Sharing Analysis By J-Logger

TABLE 1Percentage Load Sharing By Experimentation Using J-Logger

SR. NO	LOAD (KG)	TORQUE (N-MM^2)	LOAD SHARING (%)		
			PIN 1	PIN 2	PIN 3
1	0	0	31.6821	42.2428	26.0749
2	0.5	2918	32.8421	42.3250	24.8328
3	1	5836	32.9863	42.3027	24.7108
4	2	11673	32.7764	40.3609	26.8625
5	3	17510	32.4630	39.8869	27.6501
6	4	23347	32.0189	39.3866	28.5944
7	5	29184	34.9258	37.5398	27.5343
8	6	35021	35.2529	36.8676	27.8794

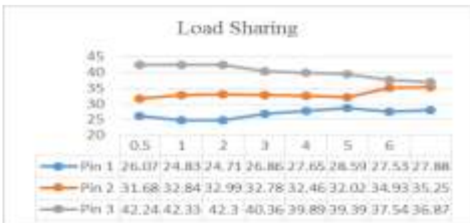

Fig. 5 Load Sharing Analysis Of Planetary Gear Set By J-Logger

As The Panopticnode J-Logger Doesn't Give The Exact Stress Values On The Planet Pins Only Load Sharing Analysis Can Be Done As Only Relative Values Are Needed For The Load Sharing Analysis Fig.5 Shows The Percentage Load Sharing Which Is Calculated From The Values Measured By Panopticnode J-Logger By Varying The Load. Pin 3 Shows More Load Than Pin 1 And Pin 2. Pin 1 Shows Minimum Load.

Comparison of Theoretical Stress and Experimental Stress Measured By DEWE-43 DAQ

TABLE 2Comparison Between Theoretical Stress And Experimental Stress Measured By DEWE-43 DAQ

Sr. No	Load (Kg)	Theoretical Stress (N/Mm^2)	Experimental Stress (N/Mm^2)		
			Pin 1	Pin 2	Pin 3
1	0.5	1.8	1.592	1.872	1.935
2	1	2.03	1.946	2.163	2.332
3	2	4.06	3.886	4.265	4.664
4	3	6.09	5.903	6.556	6.797
5	4	8.09	8.068	8.461	8.823
6	5	10.16	9.702	10.677	11.122
7	6	12.19	11.806	12.778	13.479

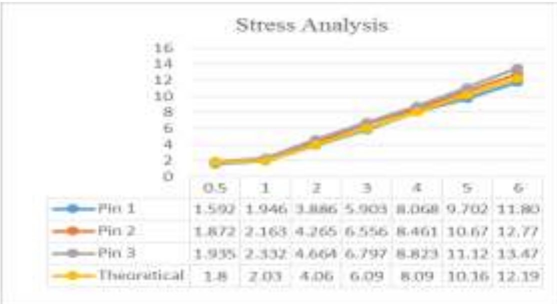

Fig. 6 Comparison Between Theoretical Stress And Experimental Stress Measured By DEWE-43 DAQ

Fig. 6 Gives The Comparison Between Theoretical Stresses And Experimental Stresses For Various Loads. It Can Be Clearly Concluded That As Load Increases Stresses In The Pin Also Increases. Both Theoretical And Experimental Values Confirm This Statement.

Load Sharing Analysis By DEWE-43 DAQ

TABLE 3Percentage Load Sharing By Experimentation Using DEWE-43 DAQ

Sr. No	Load (Kg)	Torque (N-Mm^2)	Load Sharing (%)		
			Pin 1	Pin 2	Pin 3
1	0.5	2918	29.489	34.667	35.844
2	1	5836	30.210	33.578	36.212
3	2	11673	30.325	33.280	36.395
4	3	17510	30.655	34.046	35.299
5	4	23347	31.823	33.375	34.803
6	5	29184	30.798	33.895	35.307
7	6	35021	31.016	33.571	35.413

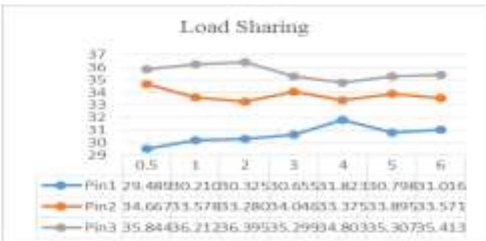

Fig. 7 Load Sharing Analysis Of Planetary Gear Set By DEWE-43 DAQ

Fig. 7 Shows The Percentage Load Sharing Which Is Calculated From The Stresses Measured By DEWE-43 DAQ By Varying The Load. Pin 3 Shows More Load Than Pin 1 And Pin 2. Pin 1 Shows Minimum Load.

FEM Stress Analysis By ANSYS Workbench

As Shown In Fig. 9 Boundary Conditions Are Applied To The Model. Fixed Support Is Given To The 8 Clamps On The Ring Gear Of The Assembly And Moments At Various Loads Are Given To The Sun Gear.

Load Case- I

Torque Applied= 2918N/Mm2

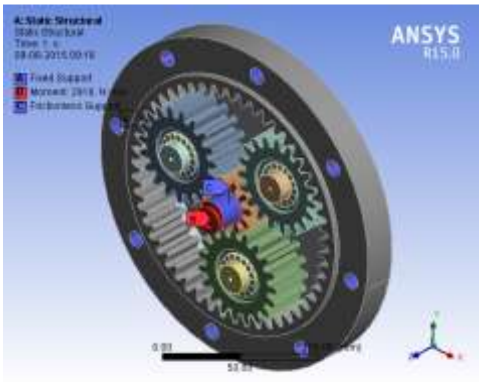

Fig. 8 Boundary Conditions For Static Analysis

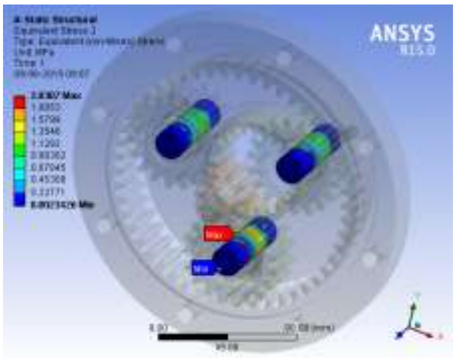

Fig. 9 ANSYS Results Of Stresses On Pin 3 For Case- I

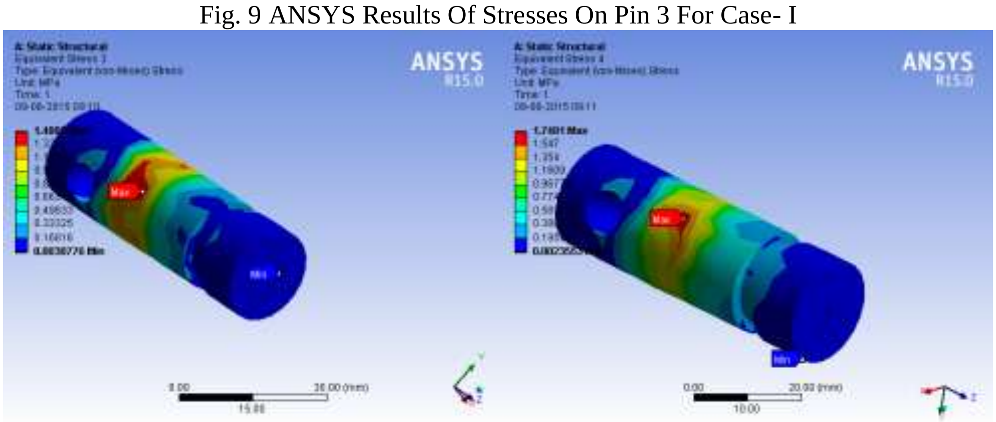

Fig. 10 Stress Distribution Of Pin 1 And Pin 2

Comparison Of Theoretical Stresses And FEM Stresses

TABLE 4Comparison Between Theoretical Stress And FEM Stresses

SR. NO	LOAD (KG)	THEORETICAL STRESS (N/MM^2)	FEM STRESSES (N/MM^2)		
			PIN 1	PIN 2	PIN 3
1	0.5	1.8	1.489	1.740	2.031
2	1	2.03	2.026	2.313	2.665
3	2	4.06	3.878	4.161	4.848
4	3	6.09	5.717	6.298	6.847
5	4	8.09	7.891	8.289	8.986
6	5	10.16	9.507	10.154	10.915
7	6	12.19	11.561	12.157	13.517

Fig. 11 Gives The Comparison Between Theoretical Stresses And FEM Stresses For Various Loads. It Can Be Clearly Concluded That As Load Increases Stresses In The Pin Also Increases. Both Theoretical And FEM Values Confirm This Statement.

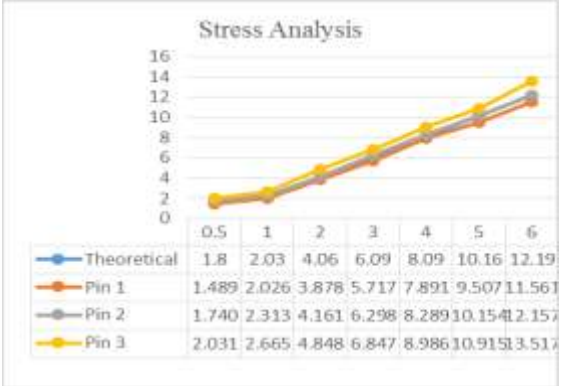

Fig. 11 Comparison Between Theoretical Stress And FEM Stresses

Load Sharing Analysis By FEM

TABLE 5Percentage Load Sharing By FEM

SR. NO	LOAD (KG)	TORQUE (N-MM^2)	LOAD SHARING (%)		
			PIN 1	PIN 2	PIN 3
1	0.5	2918	28.306	33.084	38.609
2	1	5836	28.925	33.030	38.045
3	2	11673	30.091	32.292	37.617
4	3	17510	30.311	33.390	36.299
5	4	23347	31.357	32.936	35.707
6	5	29184	31.093	33.208	35.699
7	6	35021	31.049	32.650	36.301

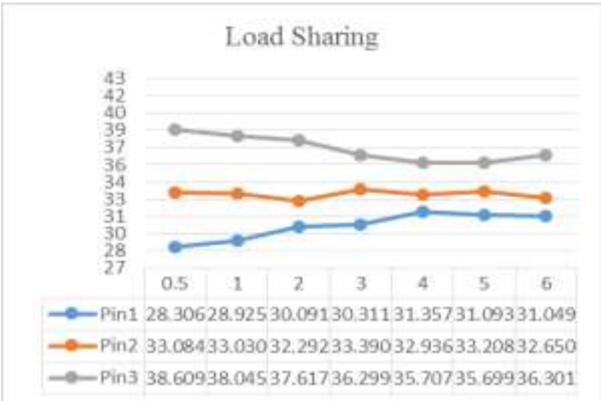

Fig. 15 Load Sharing Analysis Of Planetary Gear Set By FEM

Fig. 15 Shows The Percentage Load Sharing Which Is Calculated From The FEM Stresses Calculated By Simulation By Varying The Load. Pin 3 Shows More Load Than Pin 1 And Pin 2. Pin 1 Shows Minimum Load.

Dynamic Analysis of Planetary Gear Set

The Strain Gauges Cannot Be Pasted On Arm Pins For Dynamic Conditions. To Get Validated Results Of The Arm Pins, The Dynamic Analysis Should Be Performed On The Different Part Of The Planetary Gear Box And Validate It With Experimentation And Then The Stresses Developed On The Arm Pins Can Be Measured Using Valid Simulated Results. The Part Chosen For The Dynamic Analysis Is The Rim Of The Ring Gear, As It Is The Outermost Part Of The Planetary Gear Box And It Is Simpler Part On Which Strain Gauges Can Be Pasted.

Dynamic Simulation of Rim of the Ring Gear

In The Dynamic Analysis, The Model Of The Planetary Gearbox Is Meshed In The HYPERMESH Software And It Is Solved In The LS-Dyna Solver. The Loading Conditions Are Input Rotational Velocity

Given On The Sun Gear Is About 2500rpm And Braking Torque Acting On The Output Shaft Of The Gear Box Is About 10000Nmm.

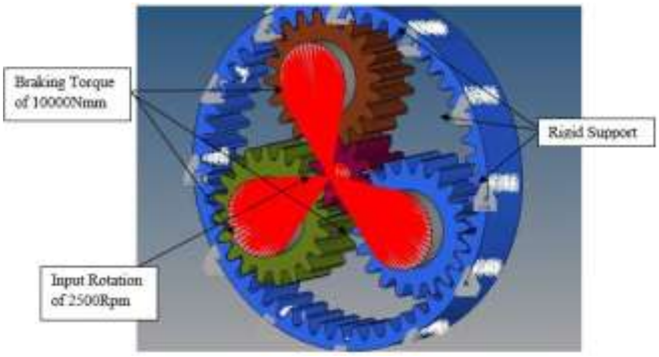

Fig. 16 Boundary Conditions Applied For Dynamic Test Setup

The Model Of The Planetary Gear Set Is Hexa-Meshed In The HYPERMESH, Using Hexa (8 Nodes) And Penta (6 Nodes) Mesh Elements. Time Step Is Given For About 5 Milliseconds.

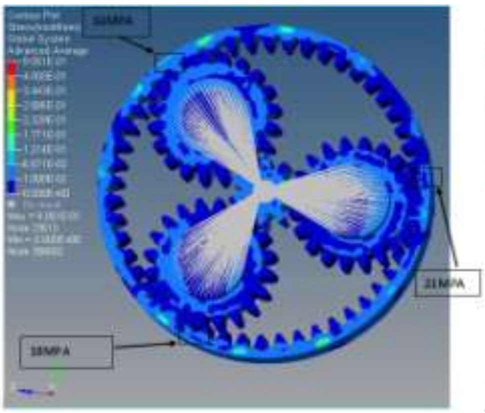

Fig. 17 Von Mises Stresses Acting After 1ms

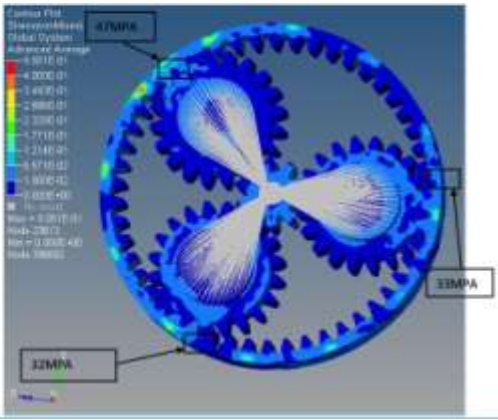

Fig. 18 Von Mises Stresses Acting After 2ms

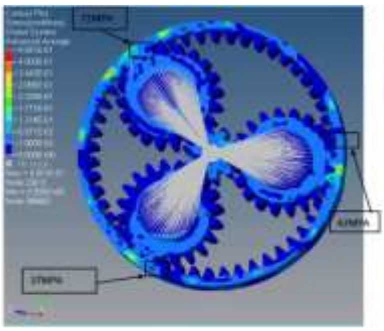

Fig. 19 Von Mises Stresses Acting After 3ms

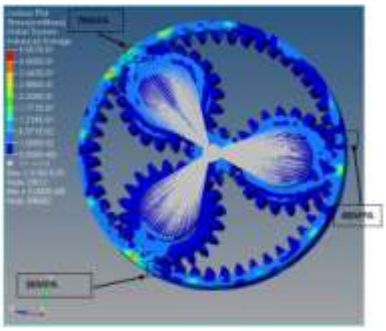

Fig. 20 Von Mises Stresses Acting After 4ms

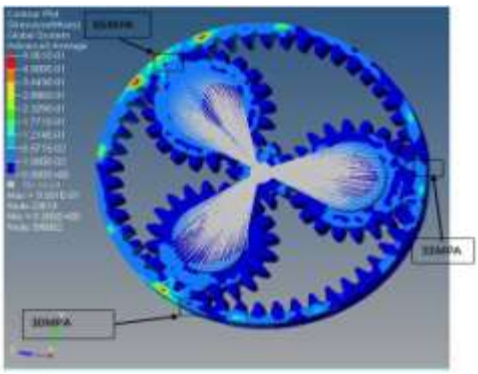

Fig. 21 Von Mises Stresses Acting After 5ms

Fig. Nos. From 17 To 21 Shows The Results Of The Equivalent Stresses Acting On The Planetary Gear Set Under Dynamic Conditions.

Experimental Results for the Rim Of Ring Gear Under Dynamic Conditions

In Experimental Analysis The Setup Had Three Strain Gauges Mounted On The Rim Of The Ring Gear To Measure The Stresses Produced On The Ring Gear Due To The Dynamic Forces Created Due To The Motor And Applied Brake Torque. The Stresses Are Measured By Using The Data Acquisition Setup Of Dewesoft DEWE-43 System. There Are Three Strain Gauges Are Attached On The Ring Gear Of The Planetary Gear Set

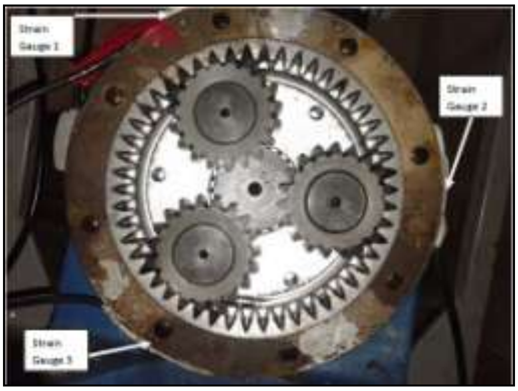

Fig. 22 Strain Gauge Location On The Rim Of The Ring Gear.

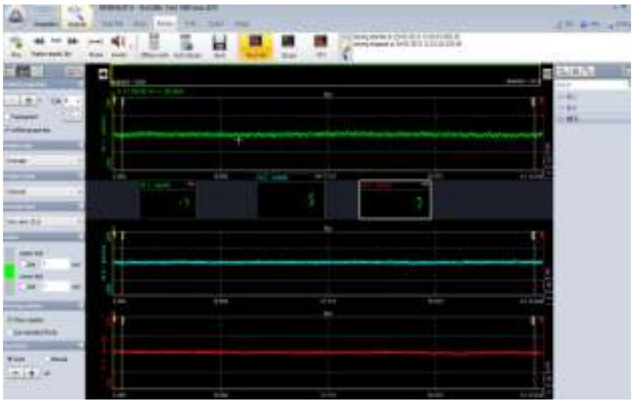

Fig. 23 Stress Measured By DEWE-43 DAQ At 2500 Rpm And 10000Nmm Brake Torque.

The Experimentation Consists Input Rotation Speed Of The Motor Kept Constant At Around 2500 Rpm And Braking Torque For About 10000Nmm Is Applied. The Stresses Generating On The Rim Of The Ring Gear Are Directly Measured On The DAQ System. As The Strain Gauges Are Pasted On The Rim Of The Ring Gear At 120º From Each Other, The DAQ System Will Give The Exact Stress Values For The Required Condition. The Reading Are Taken For 1 Min Of Loading After The Setup Is Kept Running For Half A Minute To Stabilize The Loads.

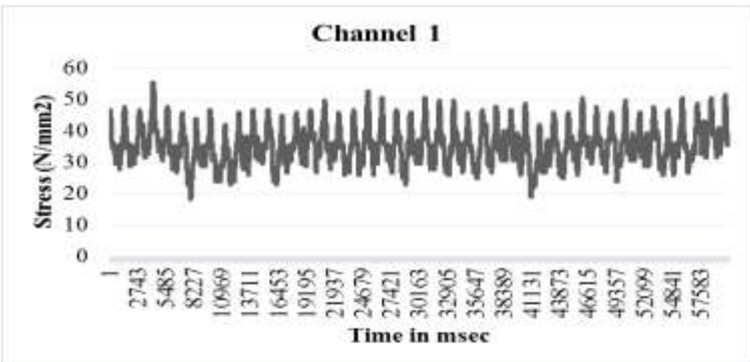

Fig. 24 Stresses Acting On The Strain Gauge-1 For Dynamic Condition

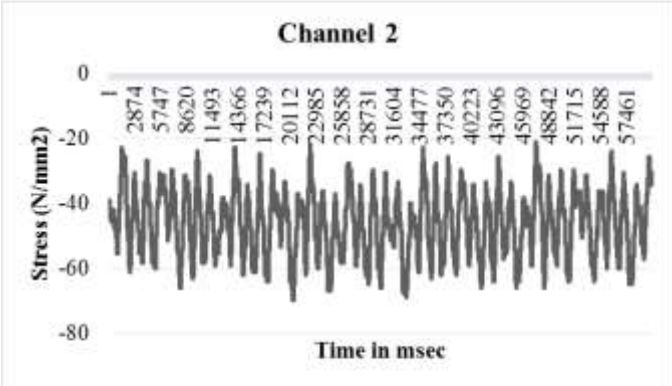

Fig. 25 Stresses Acting On The Strain Gauge-3 For Dynamic Condition

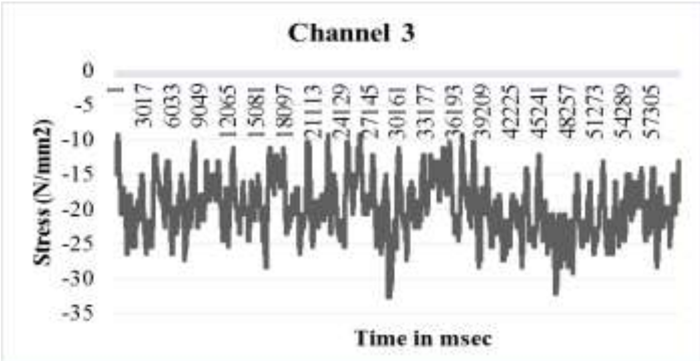

Fig. 26 Stresses Acting On The Strain Gauge-3 For Dynamic Condition

The Maximum Stress Obtained From Simulation Is About 79mpa And Maximum Stress Measured From Experimental Setup Is About 70Mpa, Which Is Close Enough To The Simulated Value

II. Results And Discussion

Static Analysis Discussion

As Panopticnode J-Logger Doesn't Give The Direct Stresses Acting On The Arm Pins, Stresses Obtained From Dewesoft DEWE-43 Are Considered For Static Analysis Discussion. Following Table Gives A Brief Idea About The Validation Of The Theoretical Stresses Obtained With The Experimental Stresses Measured By DAQ System And Simulated Stresses Done In The ANSYS 15. The Pin Stresses From All The Methods Are Very Much Close To Each Other And Hence The Validation For The Static Conditions Proved And We Have Another Method For Measuring Load Sharing Of The Planet Pins In Static Conditions.

Table 6Stresses Obtained In Static Analysis

Sr. No	Load (Kg)	Theoretical Stress (N/Mm^2)	Experimental Stress (N/Mm^2)			Stresses By FEA (N/Mm^2)		
			Pin 1	Pin 2	Pin 3	Pin 1	Pin 2	Pin 3
1	0.5	1.8	1.592	1.872	1.935	1.489	1.740	2.031
2	1	2.03	1.946	2.163	2.332	2.026	2.313	2.665
3	2	4.06	3.886	4.265	4.664	3.878	4.161	4.848
4	3	6.09	5.903	6.556	6.797	5.717	6.298	6.847
5	4	8.09	8.068	8.461	8.823	7.891	8.289	8.986
6	5	10.16	9.702	10.677	11.122	9.507	10.154	10.915
7	6	12.19	11.806	12.778	13.479	11.561	12.157	13.517

Dynamic Stress Analysis Discussion

The Simulation Of Planetary Gear Set Is Done In HYPERMESH And LS-Dyna For Which The Dynamic Conditions Are Generated Exactly The Same As Those Used For Experimental Readings. The Only Slight Difference Is That The Simulation Is Run For Only The Time Step Of 5milliseconds, But This Time Step Is Very Much Sufficient To Get The Required Results As One Whole Tooth Mesh Take Place In Less Than 5msec. The Results Obtained From The Simulation Are Such As, The Channel 1 Gives Maximum Stress Value Up To 47MPA, 2nd Channel Gives The Maximum Stress Value Of 79MPA And 3rd Channel Gives Maximum Stress Value Of 40MPA.

The Result Obtained From The Dynamic Experimentation Of The Rim Of The Ring Gear Validates The Results Obtained By The Simulation. The Readings Shows That The Range For The Stresses Measured By The Channel 1 Is About 18MPA To 55MPA, While Channel 2 Gives The Readings In The Range Of 20MPA To 70MPA And The Channel 3 Gives The Stress Values In The Range Of 9MPA To 33MPA.

As The Results Obtained From The Simulation And Experimentation Validates With Each Other, It Is Clear That The Stresses Generated At The Planet Pins Of The Gearbox Are Also Valid Stresses, Which Can Gives The Load Sharing Analysis Of The Planet Pins At The Dynamic Conditions.

Dynamic Stresses Developed In Planet Pins

Fig. No. 42 Shows The Dynamic Stresses Developed In The Arm Pins Under The Dynamic Load Conditions Of Input Rotations Of 2500rpm And Braking Torque Of 10000Nmm

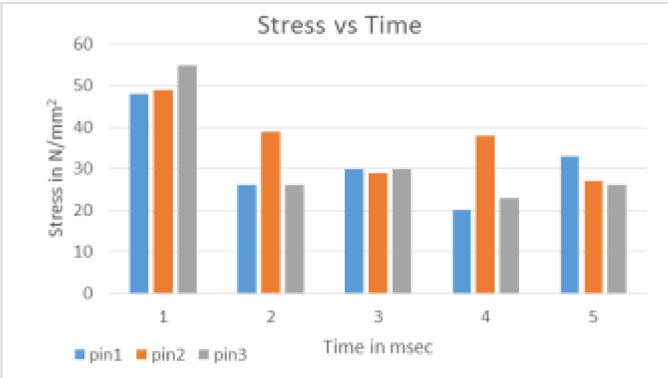

Fig. 27 Dynamic Stresses Developed In The Arm Pins

The Load Sharing Analysis Of The Planet Pins Under Dynamic Conditions Is Shown In Fig. No. 43. As The Results Of The Dynamic Simulation Are Validated, The Results For The Load Sharing Are Also Valid. Hence The Load Sharing Of The Arm Pins Can Be Calculated Under The Dynamic Conditions Also.

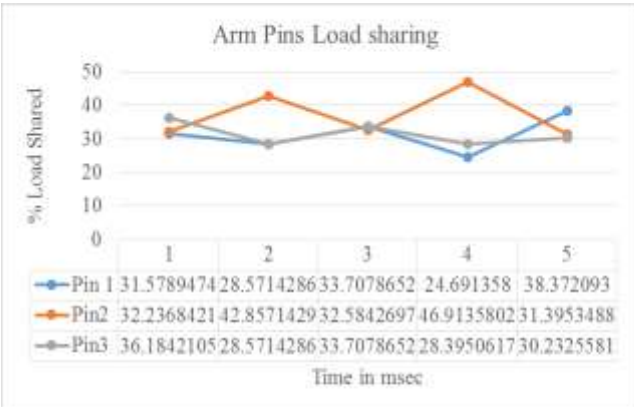

Fig. 28 Dynamic Stresses Developed In The Arm Pins

III. Conclusion

The Load Sharing By The Stress Variation By Analytical Is Assumed To Be Evenly Distributed But From The Experimental And Simulated Results For Load Sharing Shows That Pin1 Doesn't Take As Much Load Compared To Other Two. But As The Torque Increases The Load Sharing Intend To Become More Even.

In The Dynamic Conditions Also The Stresses On The Rim Of The Ring Gear Are Validated By The Dynamic Simulation Of The Planetary Gear Set For The Same Dynamic Conditions.

The Valid Dynamic Results Of The Planetary Gear Box Concludes That The Load Sharing For The Dynamic Conditions Also Valid. Hence The Way To Calculate The Load Sharing Is Valid.

Future Scope

In The Future The Project Work Can Be Succeeded By The Work To Be Done On The Fatigue And Crack Analysis Of The Planetary Gear Set.

Also The Vibration Analysis Of The Planetary Gear Set To Find The Exact Crack Position By Using The Same DAQ System Also Has A Very Large Scope In The Future In The Field Of Noise, Vibration And Harshness.

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