THE RESULTS OF MODELING AND TESTING OF HARMONIC DRIVE.

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Summary: Department of Production Machines and Mechanisms of FME CTU in Prague have been investigated Harmonic Drives for many years. Evaluation of abrasive wear and damage of the drive due to the cyclic loading requires detailed description of force/stress acting on the drive single parts. This paper is aimed at the strength evaluation of flexible, toothed, thin-walled, cylindrical cup of Harmonic Drive. Global model of this Flexspline has been developed by means of Finite Elements Method at the base of its analytic stress solution and the strain-gauge measuring of Flexspline has been realized at the same time. Flexspline and outer ring of flexible ball bearing are modelled as deformable shells, Circular Spline (rigid ring with internal teeth) and wave generator as absolutely rigid bodies. Flexspline teeth are modelled as plates interacting with Circular Spline teeth. The model is loaded by prescribed rotation of a wave generator. Computed stress has been evaluated using strain gauge measurement. This paper follows on the article presented in extended summaries of 17th Danubia-Adria Symposium on experimental methods in solid mechanics. The results of harmonic drive’s investigation are described.

Introduction.
The article presented in extended summaries of 17th Danubia-Adria Symposium on experimental methods in solid mechanics described in detail FE model of Harmonic Drive PH 80 - 100. Experimental investigation of this drive has been also done to verify numerical calculation. This paper is focussed on the results of this investigation. It contains results of computation, experimental measurement and their comparison.

FEM computation.
Analytical solution, developed earlier, has been useful only for computation of critic place of shell of Flexspline but not for describing of complex stress state. To improve design of Flexspline of Harmonic Drives the methodology of FEM computation has been developed. It is applicable for design of other drives.

The diagrams of stress distribution have been processed. Work /1/ in detail describes those diagrams made for external and internal surface. The light places in fig. 1 show the peaks of circumferential stress on the external surface of cup shell of Flexspline. This places correspond with places of mesh of Flexspline and Circular Spline.

Experimental investigation of drive.
Harmonic Drive has been experimentally analysed. The reason of this analysis is to verify numerically determined Flexspline stress field and operational parameters (input and output angular speed and torsional moment interdependence) of the drive. Experimentally determined values have been used at a tuning time of FE model parameters such as frictional coefficients, artificial damping, clearances etc. An
example of measurement is shown in fig. 2. Output moment indicator signal (M_{out}) has been assigned to the first channel of oscilloscope, strain gauges signal (\sigma_i) has been assigned to the second one, and the third channel has been occupied by main axis indicator (synchron).

Fig. 2 shows circumferential stress and output moment dependence on angle of output shaft rotation. The two peaks distance of this curve occur to a half of one input shaft speed.

\[ \sigma \text{[MPa]} \quad M_{e} \text{[Nm]} \quad M_{n=105} \text{[Nm]} \]

\[ \text{Value of tangential stress,} \quad \text{the distance from the bottom of wave disk is 51 mm} \]

\[ \text{loading of output shaft} \quad M_{e}=100 \text{[Nm]} \]

\[ \gamma_{\text{experiment, peak-3}} \quad \gamma_{\text{experiment, peak-2}} \quad \gamma_{\text{calculation by FEM}} \]

\[ \text{Conclusion.} \]

The methodology of Harmonic Drives modeling has been successful. Maximal values of all computed stress distribution are not critical. Experimental investigation has verified FE model successfully. The model is useful for next calculations of other problems of Harmonic Drives.

\[ \sigma_i \text{curve in fig. 3. is in fact detail of } \sigma_i \text{curve in fig. 4, but it has been measured independently.} \]

**Comparison of computation and measurement.**

To verify FE model the results of experimental strain-gauge measurement has been used. Peak 2 and peak 3 of the curve presented in fig. 3 have been used to compare measured circumferential stress dependence on input angle and computed one. This comparison is showed in fig. 4. Correspondence of curves demonstrates that the method of FEM calculation has been OK.

\[ \text{Fig. 4. Interdependence of circumferential stress on angle of input wave generator rotation (computed and measured values)} \]

\[ \text{Fig. 3. Interdependence of circumferential stress and output torsional moment on angle of output shaft rotation.} \]

\[ \text{Fig. 2. Interdependence of circumferential stress and output torsional moment on angle of output shaft rotation.} \]

**References:**

/1/ Dynybyl, V.: Evaluation of Stress of Flex spline of Harmonic Drive Unit Using Compare Methods, PhD theses, Prague 2000, Czech Republic.


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