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FACE GEAR APPLICATION ON HELICOPTER POWER GEARBOX TRANSMISSION

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ABSTRACT

The spiral bevel gear drives have been , until now , the only reliable system capable to transfer the helicopter engine power to the main and tail rotors. During the past years, most of the technological development has been concentrated on this type of gears, that could be cutted and grinded with very high precision (GLEASON). A check of the gear surface has been also developed.

The problems related to the spiral bevel gears are that generally a maximum ratio of 3 is permissible, the assembly procedure is very long and difficult , a correct contact pattern is very sensitive to gears misalignments and finally they have a very expensive production cost. For this reason the designer attention has been moved to a new gear system capable to solve the above mentioned problems.

The answer has been given with the FACE GEAR DRIVES with the simultaneous introduction of the split torque system.

A description of this new gear system is given , as well as the design procedures to generate the geometry , TCA and the consequent structural analysis .

The testing activity , presently planned in FIAT AVIO , is explained , with a description of the main objectives and rig lay-out.

An arrangement showing the application of the face gears to an existing gearbox is presented.

1. INTRODUCTION

The face gears have been a potential feature to be used in gearbox transmissions but limited to low power applications for different reasons :

- lack of a theory describing the geometry of this new type of gear
- no data/methods available to calculate the strenght of the pinion/gear
- manufacturing problems related with the grinding procedure

However the potential benefits derived from the introduction of face gears , in terms of weight and noise , have given an impulse to try to overcome all the potential problems related to their application . This paper gives the main guidelines of FIAT AVIO effort in the field :

- a description of the theory that is behind the geometrical definition
- T C A (tooth contact analysis)
- structural analysis , to be performed for a proper sizing
- testing activity, with the main objectives as well as a description of the rigs to be used
- possible gearbox configurations

2. DESCRIPTION OF THE APPLICATION

The face gear is a particular type of gear with the following characteristics :

- outer radius limited by pointing , that is a gear thickness equal to 0 in the area near the tip of the face gear itself
- inner radius limited by undercutting
- pressure angle variable from nearly 0 at the inner radius to about 40 degrees at the outer radius (see fig. 1)

These dimensions are mainly a function of the number of teeth of the pinion and the gear ratio.

The motion is transmitted from a pinion , that is a conventional spur gear , to the face gear with the axis of the two components forming an angle different from 0; in other words these two items , the spur gear and the face gear , will work as a couple of bevel gears , but with the following advantages :

- reduced sensitivity of the bearing contact to the gear misalignment

- reduced level of noise , due to the very low level of transmission errors
- favorable transfer of load from one pair of tooth to the next pair
- accurate axial location of the pinion not required .

These advantages have to be used together with the introduction of the split torque concept as in fig. 2. The split torque will be used as a particular design feature to reduce the power transmitted through each face gear : in this way a consequent reduction of the dimensions (and weight , as a consequence) can be obtained.

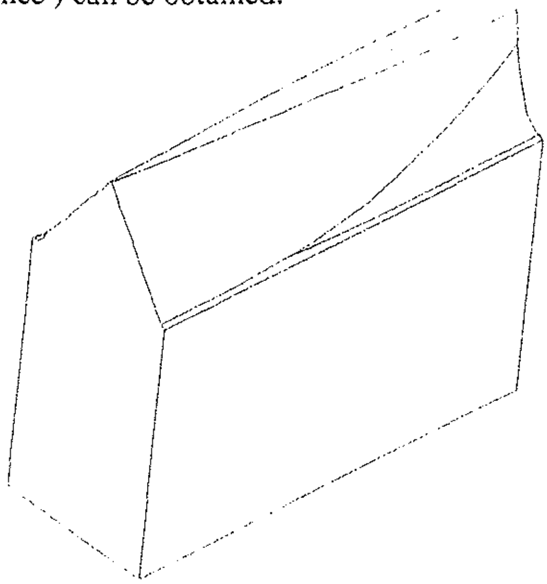

Fig. 1: Face gear geometry

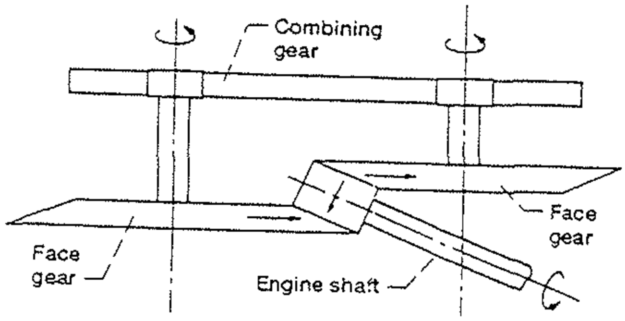

Fig. 2: Split torque

3. GEOMETRY

The geometry definition is obtained by simulating the meshing of a shaper with the face gear (see figs. 3, 4)

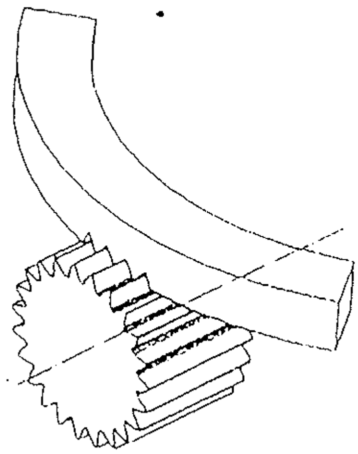

Fig. 3: face gear generation

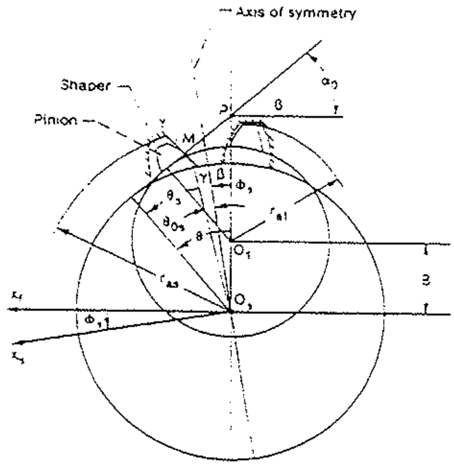

Fig. 4: tangency of shaper and pinion surfaces

The shaper has the same geometry of the mating pinion , except for the number of the teeth. This one will be increased by one,two or three , depending on the strenght or misalignment we have to substain, in order to have:

- a linear contact between the shaper and the face gear during the cutting procedure (fig. 5)
- a point contact during the meshing between the pinion and face gear

The development of the mathematical theory that allows the designer to define the main geometrical aspects is due to Litvin (refs. 1,2).

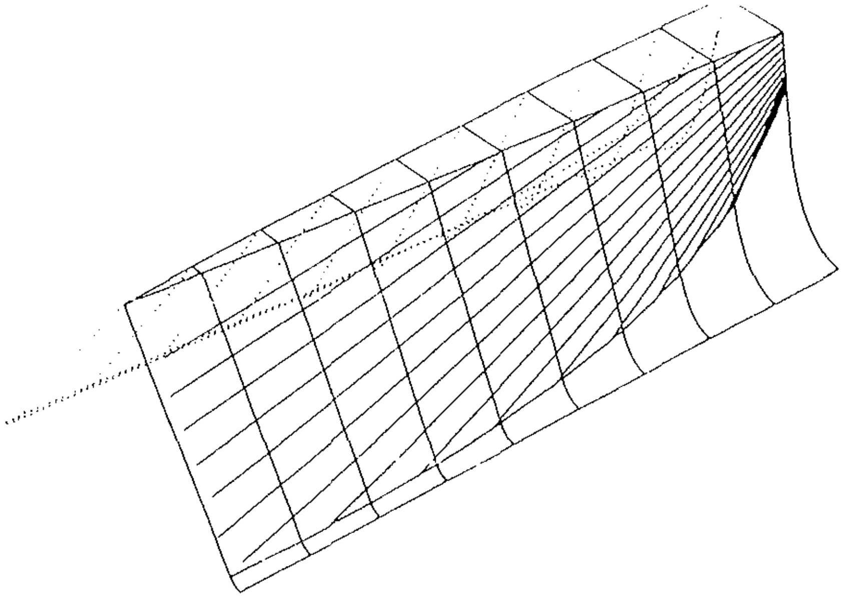

Fig. 5: contact lines between face gear and shaper

This theory is able to define the inner and outer radius (fig. 6) and the face gear surface , including the fillet radius (fig. 7).

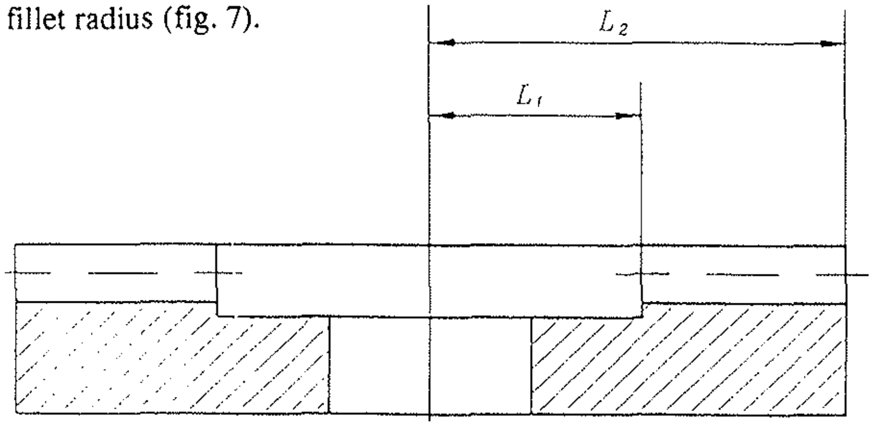

Fig. 6: face gear inner and outer radius

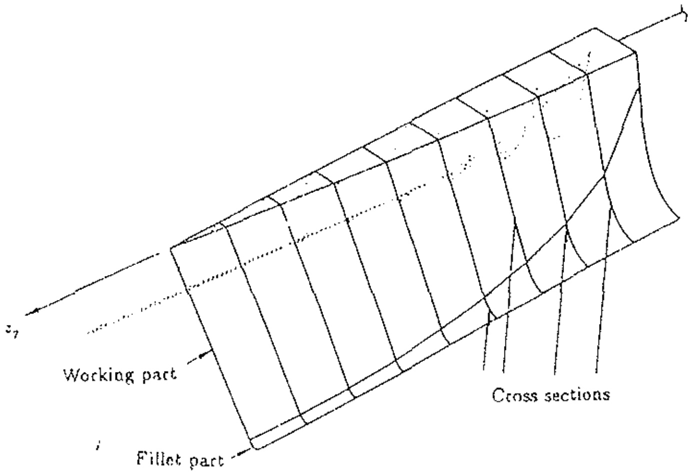

Fig. 7: fillet radius

These main geometrical features will be obtained as a function of the shaper characteristics , to be defined by the designer (two different types of shapers are in figs. 8, 9).

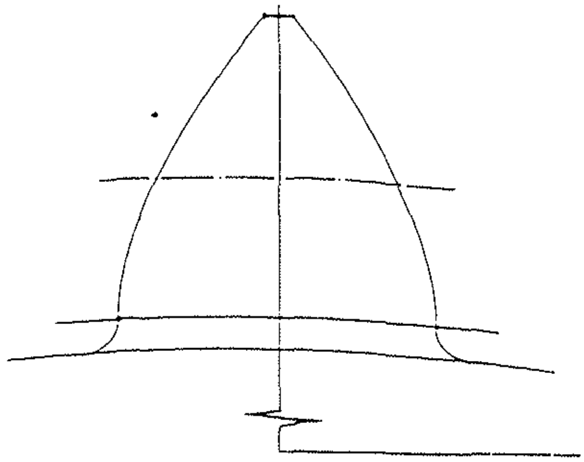

Fig. 8: shaper profile with a tip point

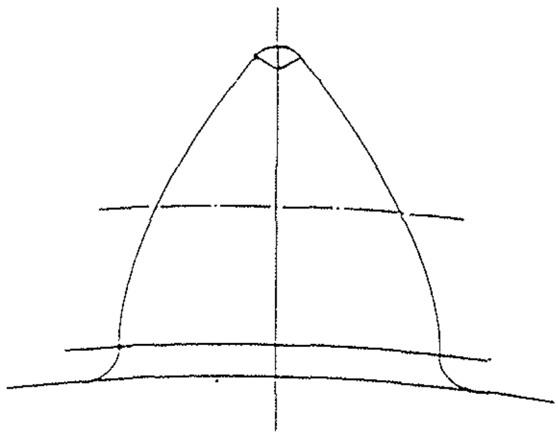

Fig. 9: shaper profile with a circular arc

When the geometry is defined the subsequent step is the tooth contact analysis (TCA). This will give the position of the bearing contact between the face gear and the pinion. Since the shaper has an higher number of teeth , with respect to the pinion , the contact will be localized in a limited area of the face gear itself (fig. 10). The contact will be function of the misalignment , manufacturing and assembly errors : as a consequence the area of contact can be moved from the inner to the outer radius of the face gear(figs. 11,12).

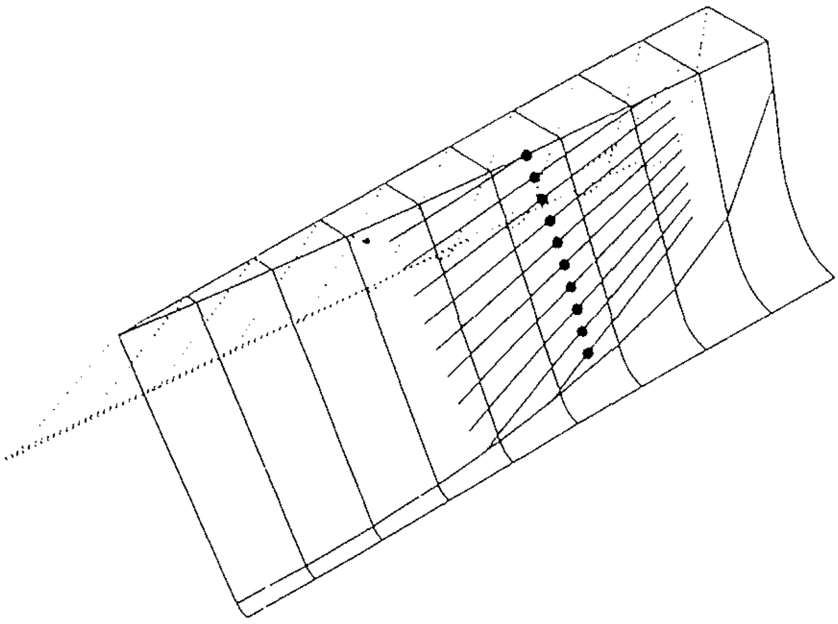

Fig. 10: contact path on the center of the face gear

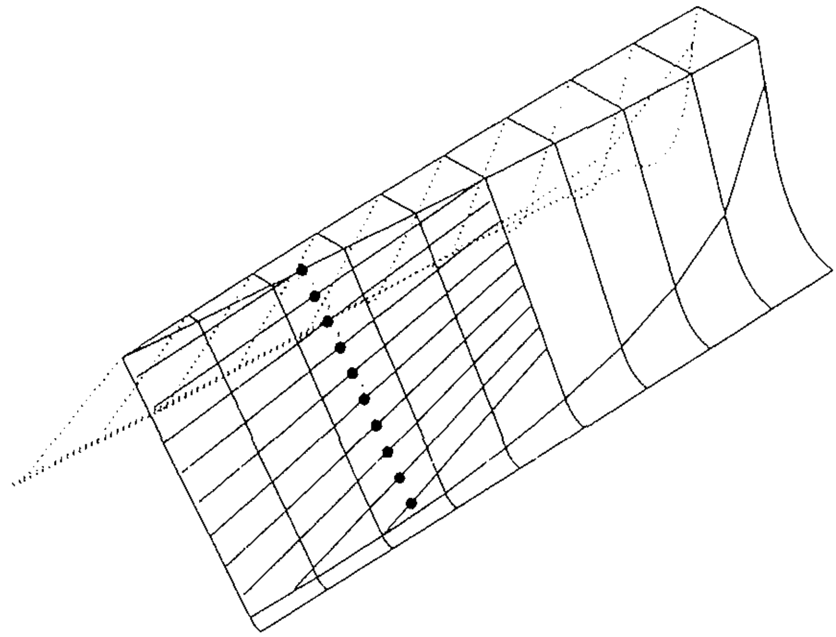

Fig. 11: contact path localized on the outer radius

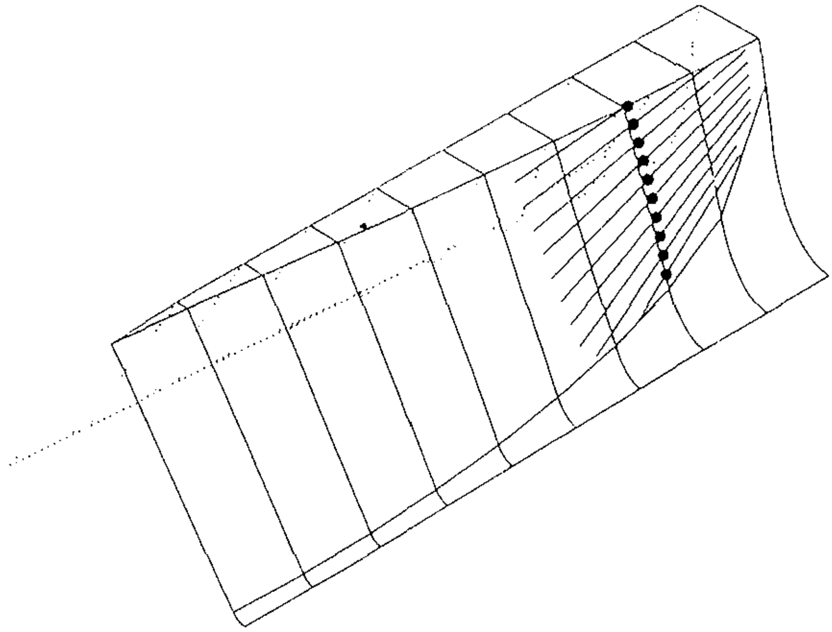

Fig. 12: contact path localized on the inner radius

4. STRENGHT

No established relationships have been developed so far to calculate the face gear strenght capability . In both stress calculations and design limits a very deep investigation is in progress (see refs. 3,4) , to give the designer the tools to define the proper geometry and dimensions of the face gear , when the operating conditions have been established. Anyway a first attempt can be found in ref 1 . A design parameter is defined , c , to obtain a rough estimation of the face gear strenght capability. This design parameter has been calculated for different geometries, in terms of gear ratio, number of teeth of the pinion, different shaper geometries, module. The main results are summarized in fig. 13. Here a strong influence of gear ratio and pinion dimensions is shown : the strenght increase is a direct consequence of the face gear dimensions , and have the drawback in bigger dimensions , as well as in weight.

Anyway a preliminary boundary in the face gear introduction can be found here: a value at least equal to 10 has to be calculated , to obtain all the benefits with respect to the bevel gear application.

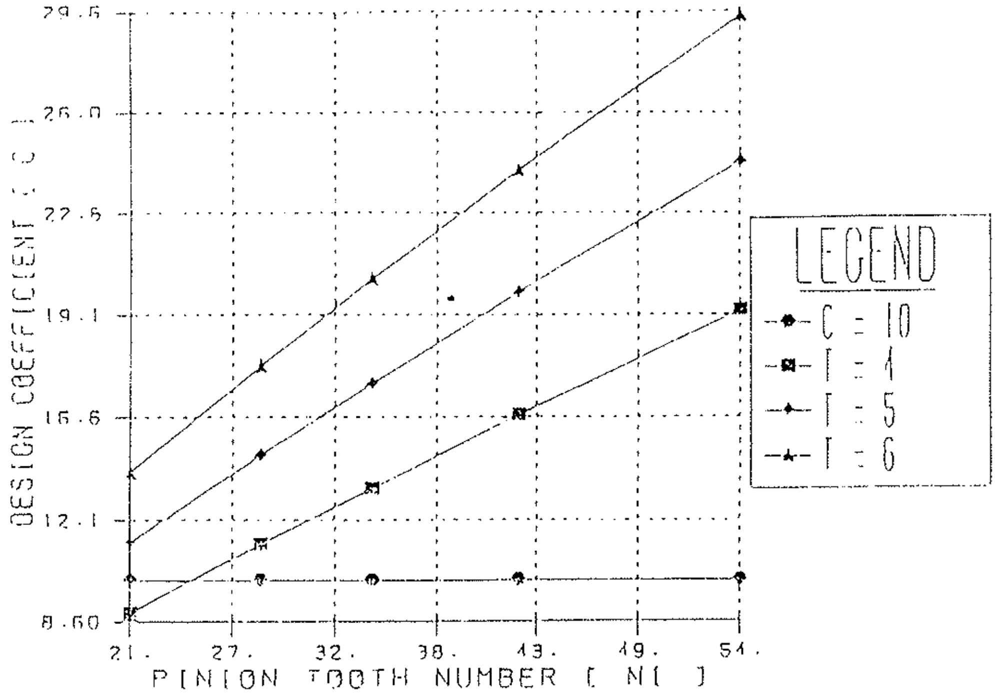

Fig. 13: design parameter

The design will be supported by using finite element models. This analysis will give as output the desired compressive and bending stresses . Models like the ones in fig. 14 are used to obtain such important design data.

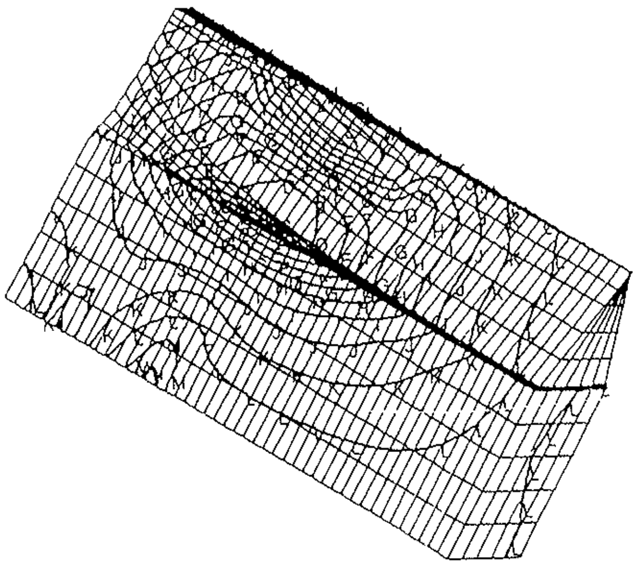

Fig. 14: finite element model

The above structural analysis will give the data for the initial design : proper experimental evidences have to be gathered to have the design validation or give the basis for successive refinements.

5. TESTING ACTIVITY

An extensive testing activity is foreseen , in order to achieve the following objectives :

-validate/verify the meshing adequacy

-define/establish the limits of application , with respect to bending and compressive stresses as well as scoring.

This will be achieved by monitoring the face gear behaviour in a proper rig, in preparation at Fiat Avio testing facility. The rig configuration in fig. 15 .

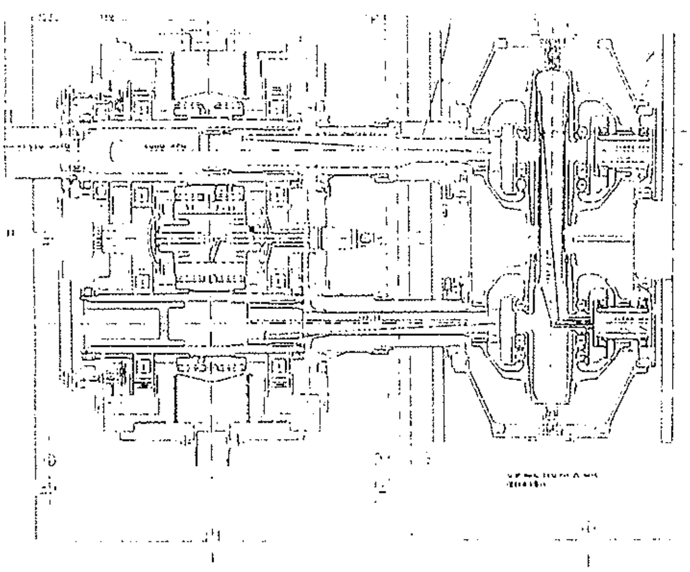

Fig. 15: face gear test rig

This rig is based on the back-to-back concept : a constant load is applied on a slave gear , that will transmit the load to two combined spur gears ; these ones will be preloaded with such a system and give the necessary preload to the set of concurrent face gears-pinions.

The face gears will be mounted with a design similar to the one used in the real gearbox application. A shaft will connect the slave part of the rig with the pinion : this will engage with two face gears , applying the split torque concept. On the opposite part another pinion will close the loop and assure the transmission of the total power to the next couple of face gears . A more detailed study is shown in fig. 16.

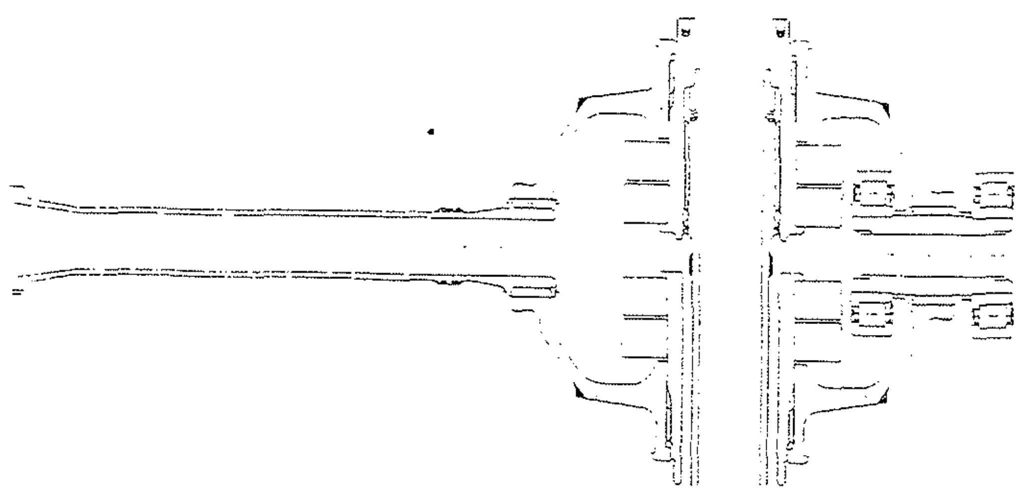

Fig. 16: face gear rig detail

6. APPLICATIONS IN HIGH POWER TRANSMISSIONS

The application of this new gear technology has to be foreseen together with the split torque concept. Trade-off studies have been carried in Fiat Avio to compare the traditional design implementing the adoption of bevel gears versus the introduction of face gears.

A configuration under study is in figures 17,18, where starting from the present design , the new concepts have been applied .

Here we have a gearbox system (fig.17) that can be used to transmit the motion from the two engines to the main rotor; besides the motion can be transferred to the different helicopter accessories.

As it is visible , two split torque systems are used ; the total motion reduction has been done using two stages , to obtain the final main rotor movement.

A 3 D view of the proposed configuration is in fig. 18. This model has given the basis for the trade-off , with respect to the present design.

In this case the overall constraint is the avoidance of major redesign for the existing parts: anyway a total weight reduction of 14% has been calculated.

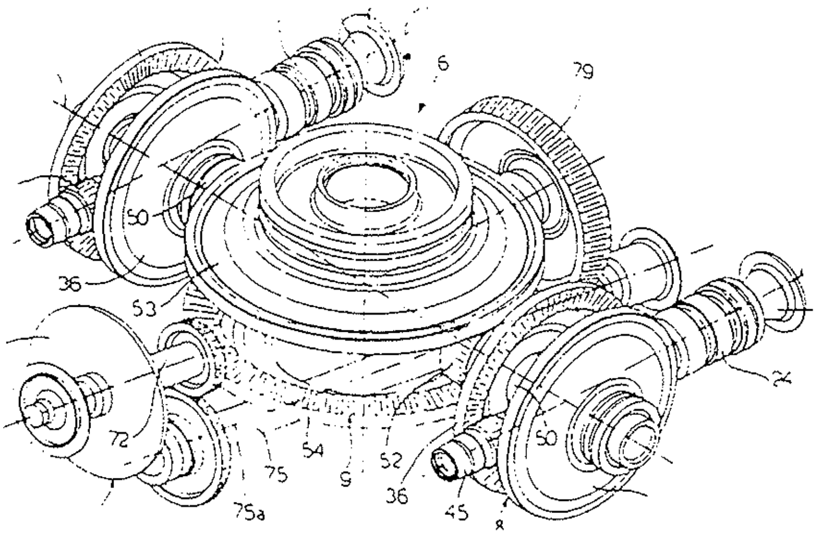

Fig. 17: gbx design configuration

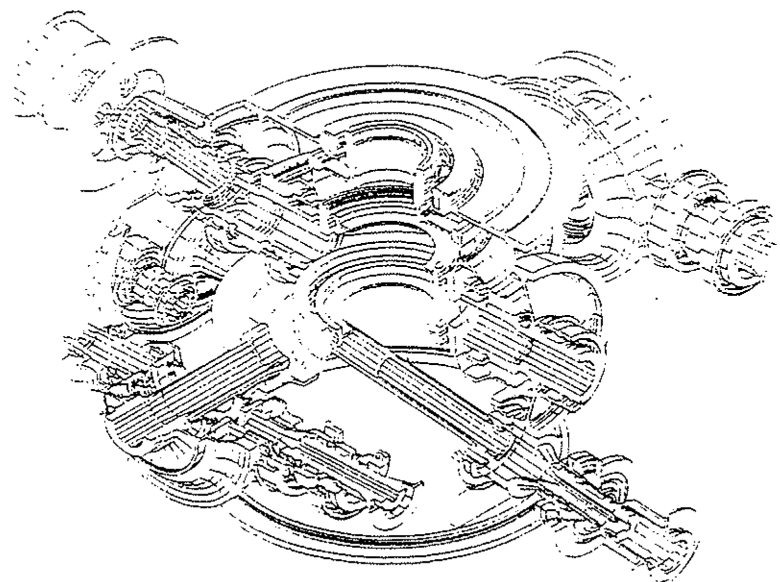

Fig. 18: gbx design configuration

7. CONCLUSIONS

The main design procedures to support the introduction of face gears in high power gearbox transmissions have been outlined , covering:

- main geometrical characteristics
- geometry definition and TCA
- structural analysis

Extensive testing activity has been already planned in FIAT AVIO , to validate the above procedures and support the introduction of these new gears in helicopter transmissions.

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