SPACEGEAR State of development
May 2003

REPORT SPACEGEAR
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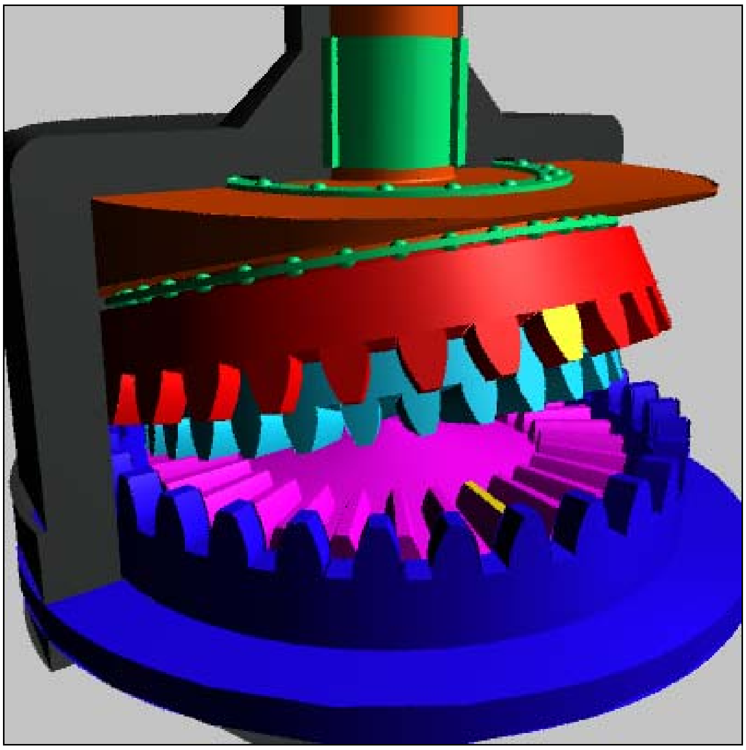

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1 INTRODUCTION

SPACEGEAR is an innovative gear drive train system for applications where high reductions ratios are needed. The technology builds on work has been previously carried out at STAM for the space industry.

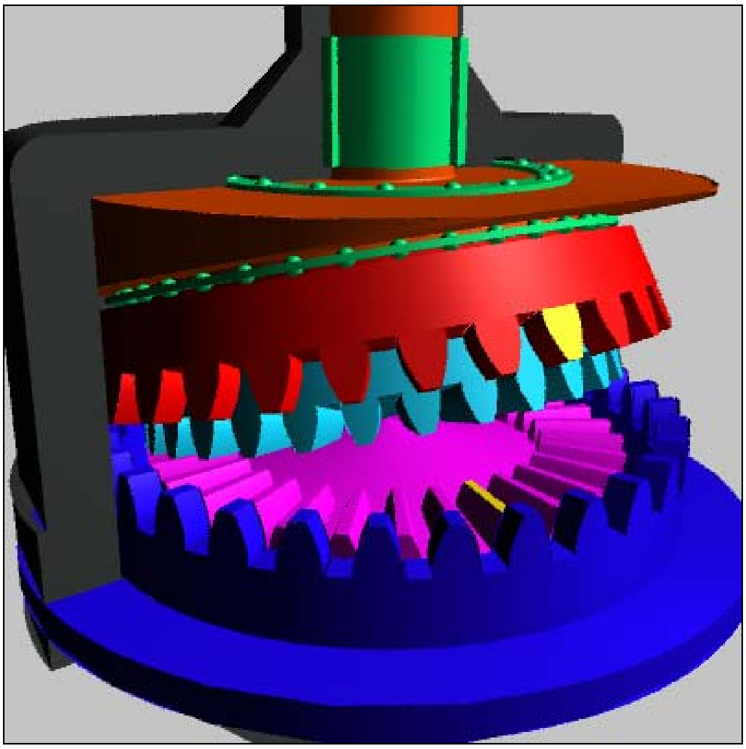

Figure 1: Cad representation of SPACEGEAR

This gearbox system is based on the mathematical concept of nutation coupled with bevel gears and is applicable to speed reduction ratios in the range from 10 to 3000.
Such gear drive-train system has the following advantages:

- simple configuration only four gear which leads to a reduction of manufacturing cost;
- multiple tooth engagement, which reduces the need for high-strength gear material, allow high torque transmittal

capability, and increase the reliability of the system;

- SPACEGEAR exhibits a higher efficiency than other competing systems;
- SPACEGEAR may operate with essentially zero backlash.

The main geometrical parameters are shown in Figure 2

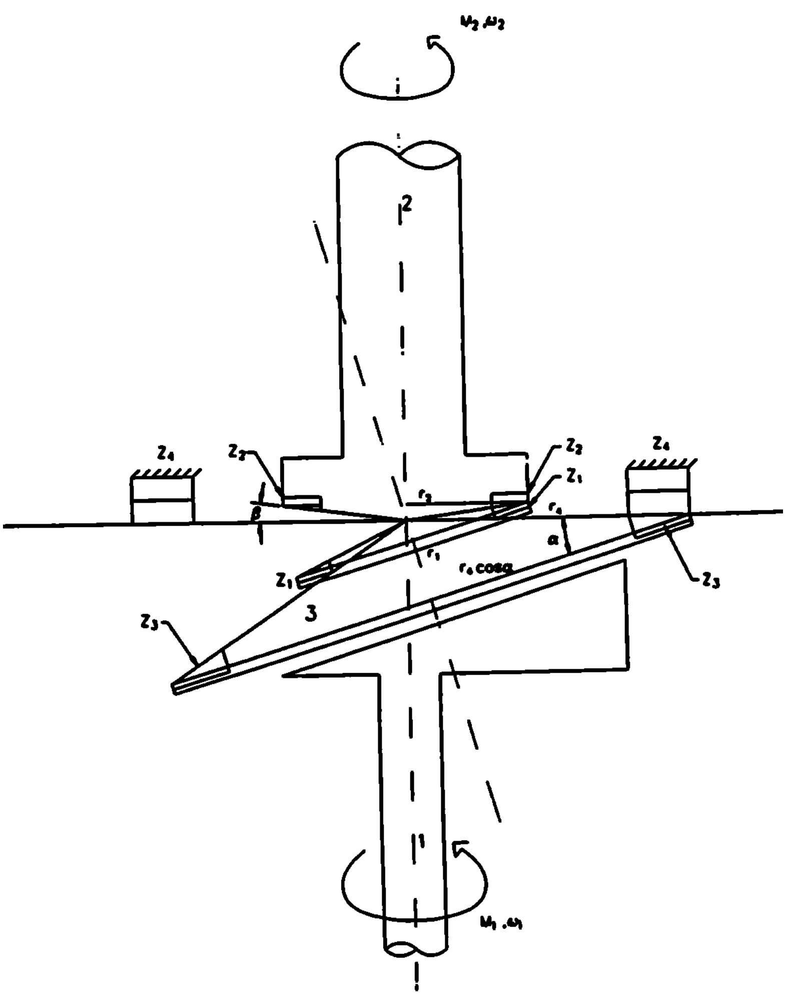

Figure 2: Geometrical parameters of the Nutating Gearbox

The following definitions are applied:

- the input shaft 1 has rotation speed ω_1 and torque M_1;
- the output shaft 2 has rotation speed ω_2 and torque M_2;
- the input gear, indicated as 3, has number of teeth z_3; the reference cone of the input gear forms an angle α with the plane perpendicular to the input shaft;
- the driving gear, fixed on the input gear, has number of teeth z_1; the reference cone of the driving gear forms an angle β with the plane perpendicular to the input shaft;
- the fixed gear, mating with the input gear, has number of teeth z_4;
- the output gear, mating with the driving gear, has number of teeth z_2.

2 THE NUTATING GEARBOX

2.1 CONTACT RATIO

To assure continuous smooth tooth action, as one pair of teeth ceases action a succeeding pair of teeth must already have come into engagement. It is desirable to have as much overlap as possible.

The minimum amount of contact that will be adequate depends upon many conditions, and may need to be established by experience or experiment for critical cases.

A measure of this overlap action is the contact ratio.

It is good practice to maintain a contact ratio of 1.2 or greater.

A contact ratio between 1 and 2 means that for a part of the time two pairs of teeth are in contact and during the remaining time one pair is in contact.

A ratio between 3 and 4 means that two or three pairs of teeth are always in contact.

Figure 3 shows the contact ratios obtained for the internal (i.e. gears 1 and 2) and external gears (i.e. gears 3 and 4) of the nutating gearbox .

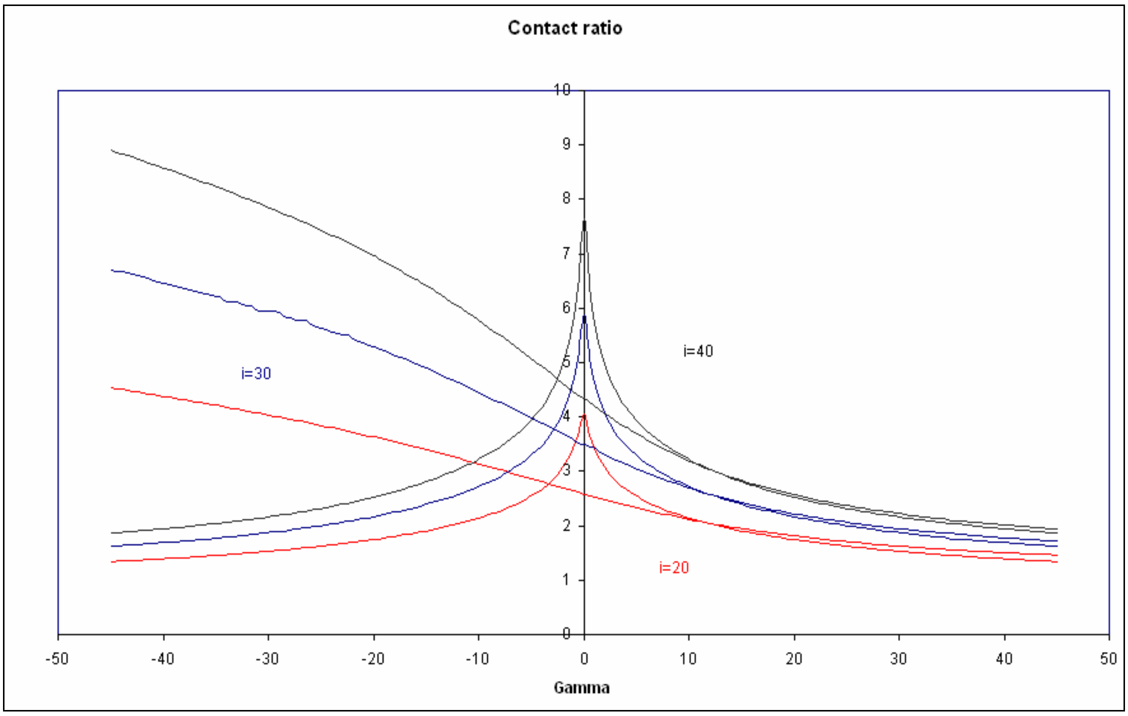

Figure 3: Contact ratios

In an involute gear system the number of teeth in contact is generally one. For a short period of time, two teeth are in contact. This creates a stress concentration especially in the root area.

In SPACEGEAR the load is distributed to a large number of contact points and then it does not create root stress. For the generic configuration the number of contact points is 10-15% of the number of the teeth; for the standard configuration the number of contact points is up to 20% of the number of the teeth.

2.2 POWER-FLOW ANALYSIS

One widely used technique for determining the efficiency of a gear train is to compute gear mesh losses using a power flow analysis assuming steady-state operation of the train (i.e. zero angular acceleration). These losses, represented using an efficiency coefficient η, are due only to sliding in the gear mesh and do not account for viscous losses or losses in bearings.

The power-flow approach to efficiency analysis is useful and flexible since, unlike velocities, torques and powers can be considered independently of the motion of the observer

The global efficiency of SPACEGEAR system is function of different factors, but in the first place the efficiency depends on the transmission ratio and on the elementary efficiency of singular gear pair.

Once the gear-pair efficiency is known, it is possible to plot the global efficiency in function of the transmission ratio.

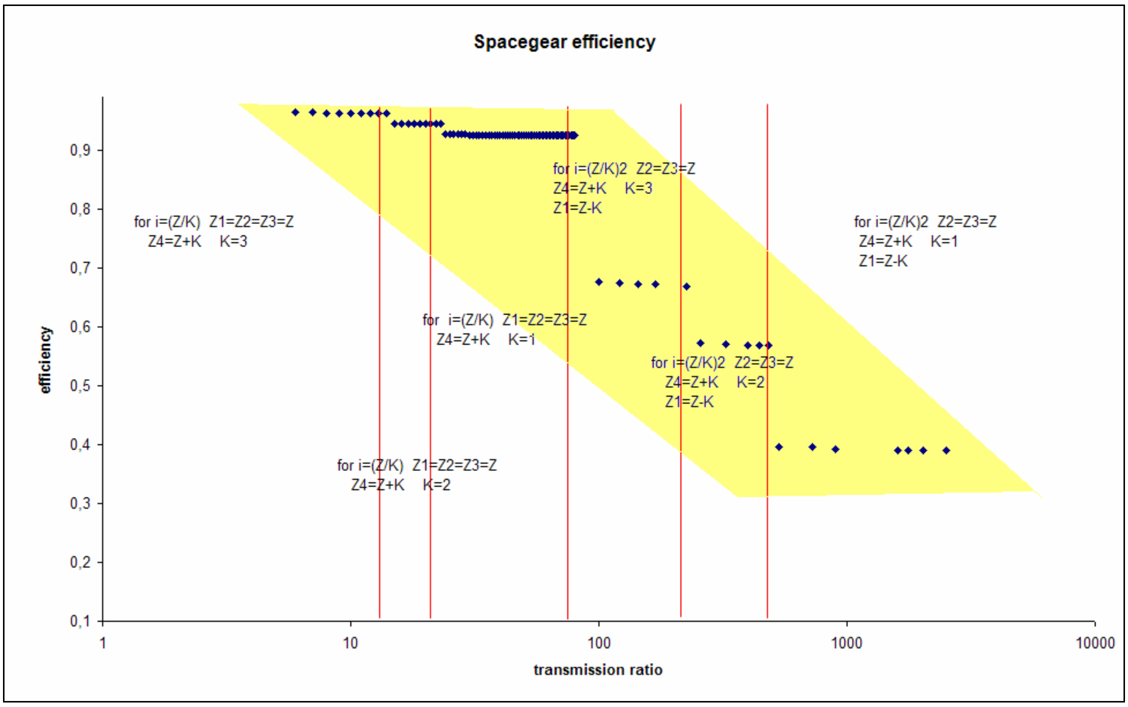

Figure 4: SPACEGEAR efficiency

The Figure (4) shows the efficiency in function of the transmission ratio this value is represented in the logarithmic scale. The efficiency is plotted with reference to the parameters defined in paragraph (3.3)

Figure 5: SPACEGEAR DEMO 52 and SPACEGEAR DEMO 128

Two of them have been tested and the efficiency found was slightly smaller (10%) of the one analytically determined.
These prototypes were not yet statically and dynamically balanced and this can explain the discrepancy between analytical values and the tested ones.

3 COMPARISON AMONG DIFFERENT REDUCTION SYSTEM

Manufacturers generally use two planetary gear trains in series to reduce speed and multiply torque from small electric motors. A nutating gear drivetrain could perform the same task with fewer drivetrain parts, lower-strength gear materials, higher overall reliability, and lower manufacturing cost. A review of the competitor devices has been performed as far as reduction gears are concerned. The last generation of reduction gears are based on the principle of differential action; the main typologies are:

- the Cyclo System which is based on two cycloidal disks and two eccentrics connected to the input shaft with a phase shift of 180 degrees. This system is applicable to speed reduction ratios in the range from 30 to 180. This system is however very complex and the manufacturing is therefore more expensive than for conventional gearboxes;
- the Harmonic Drive gearing which is made up of three basic parts: the circular spline, the flexspline, and the wave generator. The flexspline is a non-rigid part. This limits the application of the harmonic drive to low power application and reduction rates below 320. As a result of preloading the efficiency of the harmonic drive can be as low as 60% for low speeds and at best approach 80%. In addition to that the manufacturing of these parts requires

special technologies and process and it is therefore very expensive;

- o planetary gear trains, include several parts (at least 6) and use gears that must be made of high-strength material. The internal spur gears are hollow and require special core in machining and surface finishing. The system is therefore expensive and not intrinsically reliable.

The most direct competitor of the nutating gearbox system when high reduction ratios are expected is the epicyclical gearbox with two or three geartrains in series. In this configuration, however, the epicyclic gearbox presents the following limitations:

- o bulky size;
- o complex manufacturing;
- o high wearing of the teeth, because in the involute (gear) system the number of the teeth in contact is generally low.

TABLE 1: SPACEGEAR PROTOTYPES

No.	Name	Application	Location	i_{12}	z_1	z_2	z_3	z_4	Size [mm]	Torque [Nm]	Picture
1	SPACEGEAR SSA	Small size applications	Dapp, GE	225	28	30	30	32	Ø 105 x L 132	45	
2	SPACEGEAR MSA	Medium size applications	Dapp, GE	30	30	30	30	31	Ø 251 x L 291	3500	
3	SPACEGEAR LSA	Large size applications	Not built	66	20	22	24	26	Ø 1191 x L 1657	10^5	---
4	SPACEGEAR (VSSA)	Seat reclinining device	Dapp, GE	1024	31	32	32	33	Ø 90 x L 200	60	

(continue)

No.	Name	Application	Location	i_{12}	z_1	z_2	z_3	z_4	Size [mm]	Torque [Nm]	Picture
5	SPACEGEAR (transparent casing)	Seat reclining devices (demo)	Stam, GE	1024	31	32	32	33	Ø 90 x L 200	60	
6	SPACEGEAR DEMO 52	(demo)	ESA, NL	52	52	52	52	53	Ø 98 x L 88.5	-	
7	SPACEGEAR DEMO 121	(demo)	ESA, NL	121	20	22	22	24	Ø 48 x L 68	-	

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