AN ANALYSIS OF CRITERION FOR CHOOSING CONSTRUCTIONAL SOLUTIONS FOR AERONAUTICAL MULTI-POWER PATH GEAR UNITS

Bogdan Kozik

Rzeszów University of Technology
Faculty of Mechanical Engineering and Aeronautic
Powstańców Warszawy Av. 8, 35-959 Rzeszów, Poland
e-mail: bogkozik@prz.edu.pl

Abstract

Contemporary aeronautical constructions require applying systems of drive transmission based on gear units. Trends in development of aeronautical gears assume diminishing weight of the gear retaining its basic features which are; the possibility of transmitting high load and reliability.

The article presents an analysis of criterion for choosing constructional solutions for aeronautical multi-power path gear units. A few criteria were chosen for the analysis: constructional solutions of aircrafts (planes, helicopters), constructional solutions of engine- moment receiver system and a kind of applied drive.

Because the field of issues connected with aeronautical drive transmission systems is very wide, the material and technological factors were not taken into account. They are a subject of separate analysis.

The main aim of the presented analysis is determining the criterion for choosing constructional solutions of drives based on existing solutions which allow for implementing new solutions for newly developed aeronautical constructions on the prototype stage. Modernising existing constructional solutions is difficult to put into practice because of procedures followed in the aeronautic industry. That is why the carried out analysis aims at preparing solutions for research on the stage of making a virtual and demonstrative prototype. The final effect of such analysis and research can be developing a solution for gear unit parts assuring the possibility of transmitting a given moment while diminishing, for example, weight in comparison to gears which are produced nowadays. This factor is extremely important for parts of aeronautical constructions.

Keywords: *aeronautical gears, toothed wheels, aeronautical power drives*

1. Introduction

Gears applied in driving units of airplanes and helicopters reduce the rotating speed of engine compared to the speed of the plane’s propeller or helicopter’s rotor. Depending on the applied driving unit, the reduction can vary from 2 to 90. Reducing gears consist of one- or multistage reducers with one to three entrance shafts (depending on the number of driving engines). Gears are made from cylindrical and bevel wheels. The bevel wheels are especially applied in helicopter gears where the change of the direction of power flow is required.

Multi aeronautical gears are constructed in units of fixed axis (e.g. dual power path gear – Fig. 1a) and in units of shifting axis. The gears of shifting axis are called planetary or epicyclic gears (Fig. 1b).

The planetary gear consists of three basic parts: central external gear, a few smaller toothed wheels – so called satellites (their number depends on the transmitted power, from 2 to 9, which does not influence the value of transmission ratio) and an internal gear. The satellites are joined together by a yoke. Each part of the gear unit can drive or be driven.

2. Multipath planetary gears

Planetary gears make it possible to transmit great power and to achieve big transmission ratio having relatively small size. They have special qualities namely; transmitting torque between the central wheel and a rim with internal teeth can be done by more than one wheel which allows for sharing load. Additionally, applying internal gearing is beneficial because of small spin and the possibility of transmitting much greater load compared to an equivalent external gear.

Moreover, the epicyclic gears allow for letting the torque in and out along the same axis. That is why the epicyclic gears are widely used in driving units of planes and helicopters.

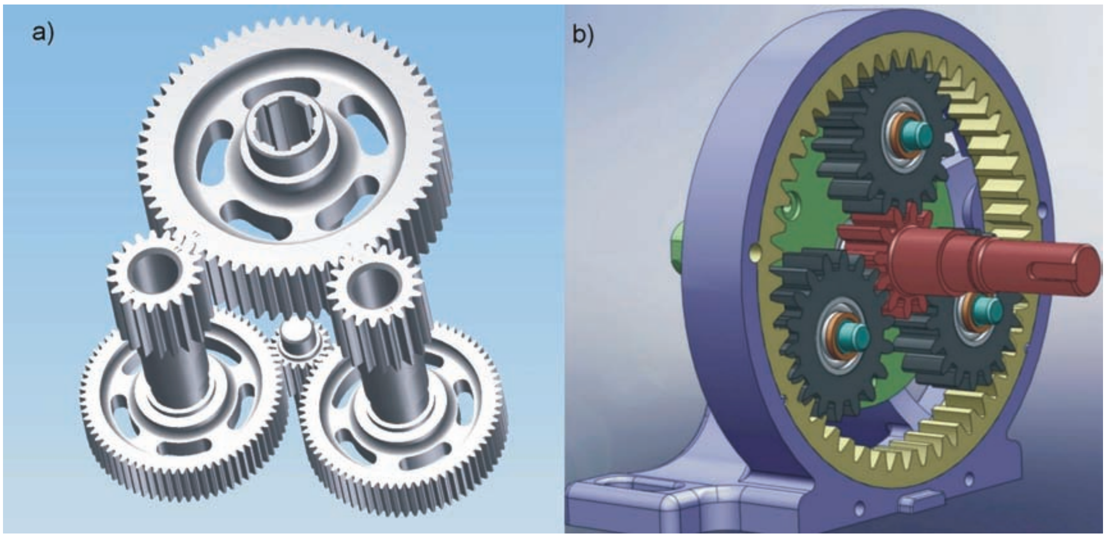

Fig. 1. 3D-CAD models of the research gears: a) dual- power path gear, b) planetary gear

2.1. Gears applied in light planes

In light planes the system of drive transmission from engine's shaft to wings of a propeller is very often constructed so that its parts were situated along one axis. An example of such a solution can be a light single-engine craft Cessna 208B Caravan used both for carrying passengers and for transporting freight. The craft is driven by a Pratt &Whitney Canada PT6A-114A engine. A chart of its driving unit with a double planetary gear is presented in Fig. 2.

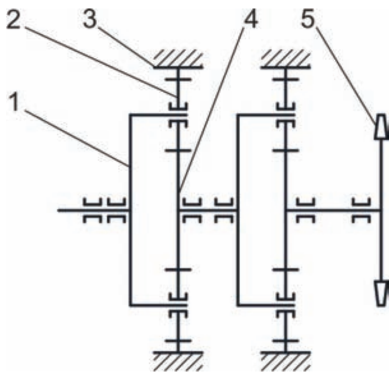

Fig. 2. A driving unit chart of Cessna 208B Caravan: 1 - planet carrier,2 - planet gear, 3 - annulus gear, 4 - sun gear, 5 - power turbine

2.2. Gears applied in medium and heavy planes

In medium and heavy planes the system of drive transmission has a greater reduction of rotating speed from engine's shaft to wings of a propeller. That is why it is necessary to apply an additional stage which most often is a reducer with cylindrical wheels. An example of such a solution can be a medium –sized, two-engine craft PZL M28B Bryza and a heavy transport airplane Airbus A400M. The PZL M28B Bryza is an evolutionary version of a light plane An-28. It is equipped with a propeller turbine TWD-10B. The Lockheed C-130 Hercules is a four-engine transport aircraft intended for taking off and landing on makeshift airstrips. Initially the aircraft was designed for carrying soldiers, evacuating injured men and transporting freight. An exemplary driving unit chart with planetary gear and an additional cylindrical reducer is shown in Fig. 3.

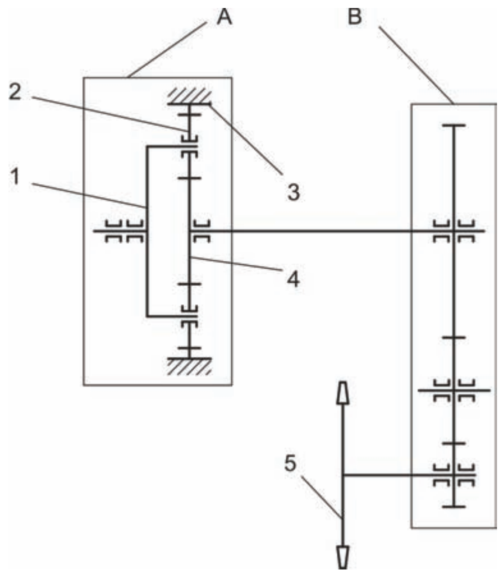

Fig. 3. A driving unit chart with planetary gear and an additional cylindrical reducer A – planetary reducer, B – high-speed cylindrical reducer, 1 - planet carrier, 2 - planet gear, 3 - annulus gear, 4 - sun gear, 5 - power turbine

2.3. Gears applied in helicopters

Reducers of carrying rotors constitute a final limiting unit of turbine power drives of helicopters. A considerable limiting can be achieved by initial limiting gears integrated with engines. A transmission ratio applied in reducers' gears of carrying rotors varies from about 0.015 to about 0.05. This is a very high ratio and can be executed in at least three-stage simple gears (or split gears) and in planetary gears with one simple stage. Because of horizontal arrangement of turbine engines in helicopters, the first stage of reducing is executed in simple bevel gear with transmission ratio of 0.4 ... 0.75.

For light helicopters the first stage of limiting can be executed by a bevel gear and the following by a planetary gear with exit on main rotors' shaft. An example of such a construction can be a light single-engine helicopter Bell 206B. A driving unit chart with bevel and planetary gear is shown in Fig. 4.

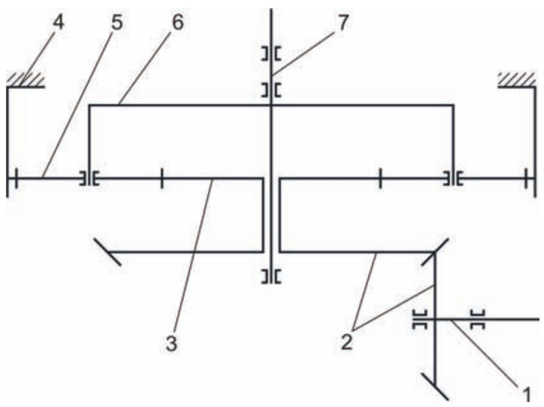

Fig 4. A kinematic diagram of main gear of Bell 206: 1 - input shaft (engine drive), 2 - bevel wheels, 3 - sun gear, 4 - annulus gear, 5 - planet gear, 6 - planet carrier, 7 - main rotor shaft

A considerable enlargement of driving unit is necessary in case of medium-sized and heavy helicopters equipped with multi-power units for example with two engines. An example of the above might be a medium-sized, two-engine helicopter W-3A Sokół and a heavy two-engine helicopter Eurocopter AS332 Super Puma Mk II. The W-3A Sokół is equipped with a four-plane main rotor and a three-plane tail rotor. The helicopter is driven by two WSK PZL-10W engines.

Super Puma has got a four-plane main rotor and a five-plane tail rotor also driven by two engines.

A diagram such a solution of driving unit is presented in Fig. 5.

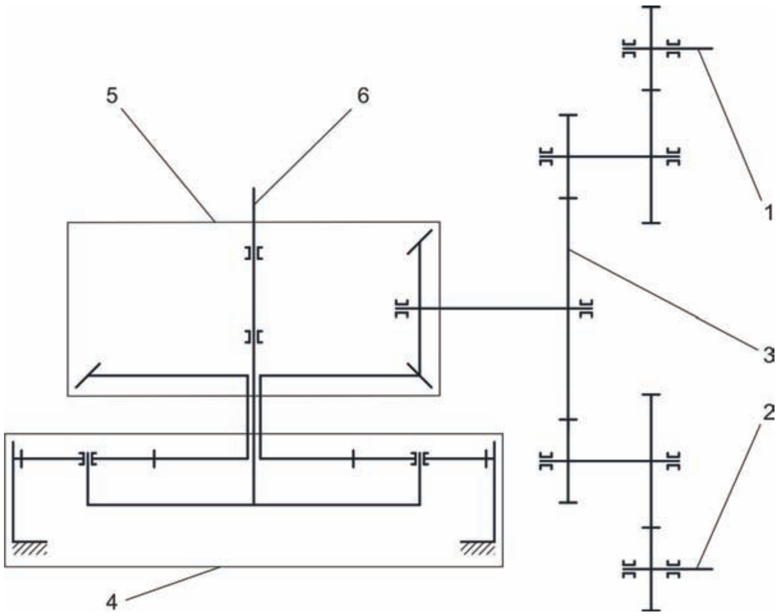

Fig. 5. A kinematic diagram of main gear of W-3A Sokół: 1 - engine nr 1 input shaft, 2 - engine nr 2 input shaft, 3 - summary gear of engine nr 1 and nr 2 power, 4- planetary reducer, 5 - bevel reducer, 6 - main rotor shaft

3. Aeronautical dual-power path gears

There is an alternative for the final stage, known as a split-torque or split-path arrangement (Fig. 6). With the split-path arrangement a final-stage reduction ratio of up to 14:1 can be achieved with two parallel power paths. Krantz [4-6] & White [10-12] has studied split-path designs for helicopters and proposed their use after concluding that such designs offer the following advantages over the traditional planetary design:

- A high speed reduction ratio at the final stage,
- A reduced number of gear stages,
- Lower energy losses,
- Increased reliability owing to separate drive paths,
- Fewer gears and bearings,
- Lower noise levels from gear meshes,
- Lower overall drive system weight.

Depending on the requirements of the rotorcraft, a split-path design can offer significant advantages over the commonly used planetary design. In spite of these attractive features, split-path designs have seen little use in rotorcraft because they have been considered relatively risky. The major risk of these designs is that even gearboxes manufactured to precise tolerances might have unequal torques in the two parallel paths.

In this paper, a split path refers to a parallel shaft gearing arrangement, such as that shown in Fig. 6, where the input pinion meshes with two gears, offering two paths to transfer power to the output gear. Designs that feature a load-sharing device such as an epicyclic torque splitter [11], balance beam [12], or quill shaft [4, 8] are not considered in this study. This study is limited to split-path designs without a load-sharing device or mechanism.

The results of this study were compared to the results of the companion experimental study. Results describing the percentage of the total torque carried by power path as a function of the clocking angle. Both the analyses and experiments indicate that power path will carry the desired 50 percent of the total torque at a clocking angle of approximately –0.001 rad.

Analyses were also conducted to predict the results of experiments done to measure the load sharing of the prototype main rotor gearbox for the Comanche helicopter. The prototype gearbox was designed for nominal clocking angles of zero for both engines.

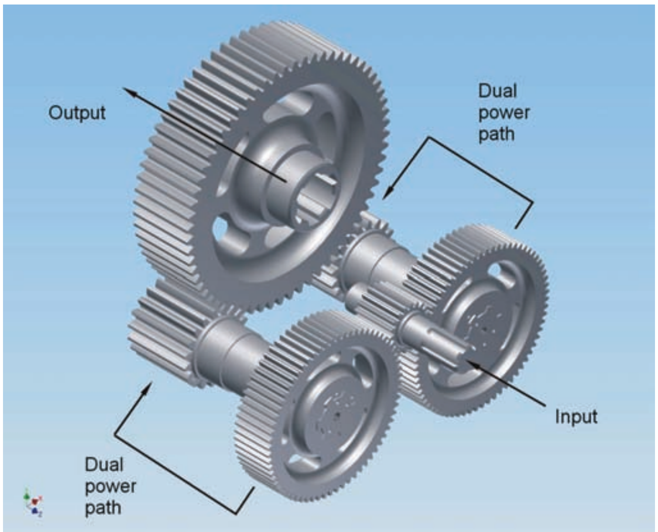

Fig 6. Example of split-path design with dual power paths

4. Conclusion

Aeronautic industry makes wide use of planetary gears in drive transmission units thanks to their numerous advantages and an experience gained so far.

The hereunder analysis shows advantages and disadvantages of planetary gears from the point of view of applying them in aeronautical driving units.

Advantages :

- great load capacity thanks to applying internal toothing,
- possibility of big reductions (to about 8 on one stage),
- split-path of power flow,
- variability of transmission ratio (immobilization of individual components in a gear),
- concentricity of input and output shaft,
- small spin especially in internal toothing,
- greater efficiency (applying internal toothing).

Disadvantages:

- big load of bearings with uneven arrangement of satellites,
- complicated assembly and operations (difficult access to components),
- complicated construction,
- uneven arrangement of load.

This study was done to better understand split-path transmissions without load-sharing devices and to support their use in future rotorcraft. An analytical method was developed to calculate the effects of deformations on load sharing. This method was applied to both the NASA split-path gearbox and the Comanche main rotor gearbox. The following results and conclusions were obtained:

- the clocking angle can be considered a design variable for split-path gearboxes. For an otherwise

fixed design, the clocking angle can be adjusted to split a design load equally between the two power paths,
- the load sharing of a split-path gearbox with two engines operating under normal flight conditions can be very different from the load sharing for emergency (one-engine-inoperative) power conditions,
- the analytical predictions compare favourably to experimental data,
- split-path transmissions without load-sharing devices can be built to maintain acceptable load sharing by using proven manufacturing capabilities. That is why these transmissions could be successfully used for rotorcraft.

Gears used in aeronautic industry are characterised by small weight in relation to transmitted power, high quality workmanship, high efficiency, reliability and durability. Therefore planetary gears are widely used especially when one needs small weight and at the same time big reduction at great transmitted power.

Additionally, applying many satellites intermediating between central wheel and an internal wheel causes multi-power path. It allows for diminishing weight and as a result of it lowering moment of inertia which is beneficial especially for frequent start-ups.

An essential parameter of planetary gears influencing their quality is the level of dividing power between satellites. The deficiency of proper division can cause that full power is transmitted by only one gearing despite applying a few satellites. Even load sharing is obtained by partly releasing one of gear parts which can middle by itself as a result of pressure forces. The central wheel is released most often (freedom of radial displacements) which causes self- middling in relation to planets. There is also a possibility of using susceptible components (e.g. the solid wheel fixed to a thin membrane) in order to compensate the displacements of satellites due to unrepeatability of workmanship errors on each of wheels. Another method can be making the toothed wheels very precisely and their susceptible bearing.

The number of teeth of gear should be fitted so that satellites are evenly placed in relation to yoke which causes that all radial and tangent powers in a central wheel and a solid wheel cancel each other out transmitting to yoke only torque and it makes easy to select bearings.

Acknowledgements

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