A NEW CONCEPT OF A SEE-SAW ROTOR

Jan Koźniewski, retired from Institute of Aviation, Warsaw, PL
Janusz Narkiewicz, Warsaw University of Technology, Warsaw, PL

Abstract

A new concept of a see saw rotor hub has been developed compromising advantages and removing some disadvantages of this type mounting of blades.

The hub is designed for rotors with even number of blades. The idea is based on joining each pair of opposite blades by an elastic element which couples their motion in flap hinges. Blades are mounted (underslung) below the plane of flap hinge axis with precone angles of pitch bearings.

Due stiffness included into the hub there are expected an increase of rotor control power, reduction of sensitivity to „blade sailing" effect and diminishing of droop angle of the blades, when there is no rotation. The underslung type of flap hinge and blade placement with precone angle reduce inplane loads from Coriolis forces.

The concept (which is now the subject of patenting process) is evaluated by considering its applicability to small size helicopter.

Introduction

See saw rotors are usually designed as two-bladed without lag hinge. They can be used both to helicopter main and tail rotors. See-saw hubs have their advantages such as simplicity of a design and freedom from a ground resonance instability.

But an application of see saw rotors is limited because of the possibility of mounting only two blades. There have also other disadvantages, such as: low control power and high in-plane vibrations. Due to a lack of a mass symmetry with respect to the axis of rotation, periodically excited motion can induce fatigue loads and noise reducing comfort of passengers and a crew.

In this paper a new concept of a see saw rotor hub is presented compromising advantages and removing some disadvantages of this type of blades mounting. The hub is designed for rotors with two or more but even number of blades.

The analysis of the applicability of the concept is presented with results of computer simulations of its dynamic and aeroelastic properties.

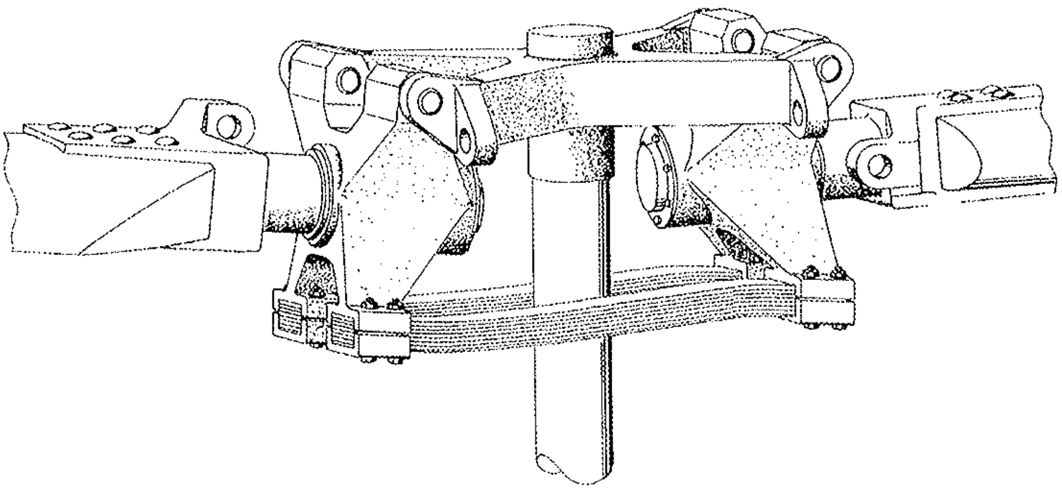

Fig. 1. An illustration of a new hub concept

Background of the concept

The concept developed is a result of an attempt to remove some disadvantages of a see-saw hub, preserving its design simplicity. The idea is to increase rotor control power for 0 g and to remove the need for lag hinge and dampers.

These goals can be achieved by application of hub with flap and pitch hinges only, where rotations in flap hinges of the opposite blades are coupled by joining them via elastic element. In this way both geometrical flap hinge offset and addition flap stiffness is obtained to increase control power comparing to classical see-saw rotor.

To reduce the lag loads the rotor pitch bearing are underslung below the plane of flap axis and precone angle. of pitch axis is applied. The possible technical realisation of the concept is shown in Fig. 1.

Description of the prospective design

The concept of rotor hub is destined to helicopters up to about 1000 kg of total mass.. The details of the design are shown in Fig.2 for a case of a four blade rotor.

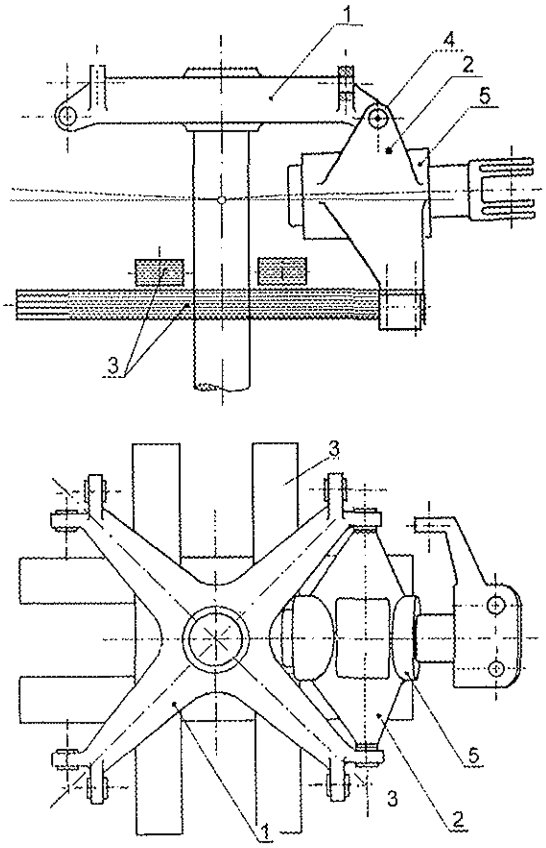

Fig.2. Details of the hub concept

The main hub elements are (Fig.2): a star-shaped main body (1) fixed to rotor shaft, four covers of pitch bearings (2) underslung to the main hub body joined by four elastic spring elements (3).

The star-shaped main body of the hub is fixed to the rotor shaft. In the case considered it has four arms. The length of the arms gives the radial offset of flap hinges from the shaft axis. The covers of pitch bearings are underslunged at tips of each pair of neighbour arms of the main body. The covers are joint to the main body by flap hinges (4). Blade pitch bearings (5) are mounted inside the covers (2) below the plane of the axis of flap hinges. The blade pitch axis have precone angles with respect to the plane perpendicular to the shaft.

The lower ends of pitch bearing covers of the opposite blades are interconnected by spring elements, designed as elastic multilayer beams. They are joint stiffly to covers, so when the flap deflection occurs, they are bent due to vertical translation of lower ends of covers. This solution allows to couple flap motion of the opposite blades and introduces stiffness into flap degree of freedom.

There is a vertical separation between elastic elements of neighbouring blades allowing the intersection of the springs. It can be obtained by shifting to different planes either upper ends (i.e. flap hinges) or lower ends (i.e. spring mounting) of the covers. In the first case the covers of all blades are identical. In the second case two types of covers are to be manufactured. The advantage of the second solution is that there will be no twisting moment of star arms. It seems that in this case also the lower total weight of a hub can be obtained.

Manufacturing details

The star hub element can be welded from steel sheets or made from light alloy casting.

The pitch bearing covers can be milled from alloy, welded from steel sheets or made form plastic composites.

The flap hinges are slide, self-lubricating type made of teflon, which lowers maintenance effort.

The interblade elastic spring elements are manufactured as packs of polished steel sheets with teflon spacers at their mounting to the covers.

Hub design

To evaluate the feasibility of the concept a rotor hub was designed and analysed for a light helicopter.

The design process had two parts. In the first part the basic hub parameters were evaluated by simple engineering methods resulting in preliminary design. In the second part the rotor motion was simulated using the more detailed model to get insight into rotor behaviour in different flight conditions.

Table I
Base helicopter and blade data

helicopter weight	668 kg
rotor diameter	7.5 m
rotor tip speed	190 m/s
number of blades	4
blade mass	9.9 kg
blade mass moment	19.25 kgm
blade moment of inertia	47.62 kgm^2
blade total geom twist	8.7 deg
aerofoils	NACA 23012
blade natural frequencies flap (1/rev) lag (1/rev) twist (1/rev)	cantilever 1.1 2.7 4.6
rotor solidity	0.0509

The helicopter and blades input data used in calculations are given in Table I. It was assumed that the blade dynamic properties had been settled at advance.

Preliminary design

Hub design parameters to be evaluated are:

- flap hinge offset
- vertical shift of pitch bearings
- precone angle
- stiffness of spring elements

The assumed constrains and criteria for selection come from considerations of:

- control power: equivalent flap-hinge offset should be about 6%
- safety: load amplitudes in spring elements should be acceptable
- weight: as low as possible.

The constraints for hub dimensions are a hub diameter between 0.2 m and 0.3 m and a hub height from 0.17 m to 0.24 m. The allowable stress in spring element is between 100 and 200 MN/m^2

The flap hinge offset for proper control power is assumed between 5%R and 8 %.R based on analysis of the data of existing helicopters.

From the steady flight simulations the mean blade flap angle of 2.2^0 is assumed. This value gives zero bending moment in a selected blade cross section in helicopter hover.

The crucial elements of the design are the springs connecting opposite blades. These are under mainly bending loads with some tension. The flight with -1g was assumed as the most critical case for loading of spring elements. The value of safety factor was taken 1.5 for the case when springs can be compressed.

The minimal thickness of a spring sheet is a result of parametric studies for given allowable stress and mean flap angle, taking a flap hinge offset as the parameter. The minimal moment of inertia for spring cross section is evaluated taking into account limits in hub dimensions, loads in „-1g flight" and safety factor. The obtained values of thickness and moment of inertia are used to calculate the width of the spring.

For given blade mass and stiffness, the rotor control power and the force in flap hinge are calculated to evaluate contributions to the control power from spring stiffness and from hinge offset. This is important for flight with negative g. Due to spring application in -0.5g flight, the control power is about 55% of that for free flapping rotor.

The results of hub parameters calculation for „-g" flight are compared with spring dimensions obtained in the first part of calculations. The first criterion is more restrictive, so it was decisive in selection of final vales.

The other values for hub operation not given in the Table II are:

- amplitude of stress in one spring layer is about 190 MN/m^2
- constant stress in one layer is 12.1 MN/m^2
- safety factor for polished layer made from steel is about 3.3.

The failure of one spring sheet gives the rise of stress in the other layer for about 4 %.

In the case of light weight helicopter the blades of four blade rotor can have the chord too small from strength point of view. The blades with planform taper (chord greater at the root) are suggested, which leads to reconsidering of the application of „minimum induced power" blade.

Advantages of the concept

The advantages expected from the new hub concept result form the additional flap stiffness, underslunging of blades with precone angles and from a lack of lag hinges and dampers.

An increase in rotor control power is expected, comparing to classic see-saw concept, as in this case control moments result both from stiffness of interblade springs and from flap hinge radial offset. Even for negative loading -0.5 g the 55% of nominal control power is preserved

An increase in rotor control power can lead to shortening the rotor shaft, reducing helicopter empty weight. Lower placing of rotor can improve its operation quality in ground effect.

Implementing interblade springs gives an increase in safety of operation at the ground due to reducing blade droop.

It can also help to diminish a „blade sailing" effect.

Low inplane moments from Coriolis forces can be expected due to underslung type of blade mounting and implementing the precone angle. The need for implementing lad hinge and dampers is eliminated.

Disadvantages of the concept

The only obvious disadvantage of the concept can be an increase of hub drag comparing to classical articulated hub, due to the greater cross-section area.

Unknown effects

The new concept allows the pairs of opposite blades to be shifted „vertically" along the shaft axis. This makes its operating conditions similar to scissors rotors and some of their advantages may occur [1]. The vertical shift of the blades also influences BVI effects. The other type of mechanisms of noise generation can also be expected, due to different shape of wake generated by two pairs of blades.

Analysis of the design

To check the hub solution obtained in the preliminary design phase the computer model developed in [2] has been adjusted to the case considered. The part of the rotor consisting of two blades is analysed

The computer model of the hub has two flap hinges with geometrical offset joined via elastic element, with pitch bearing droop and a pitch axis precone angle. The blade can bend in flap and lag directions and twist about elastic axis. The blade deflection are discretized by free rotating modes, one mode for each deflection.

The aerodynamic loads are calculated using two dimensional strip theory, with Glauert model of induced velocity and table look-up procedure for aerofoil drag, lift and moment coefficients.

The computer model consists of a set of nonlinear differential equations of rotor motion, which can be integrated within the prescribed number of rotations using Gear's algorithm.

For proper rotor operation there mainly should be checked and verified:

- air/ground resonance
- blade and rotor stability

According to the values obtained in the preliminary design phase the rotor lag frequency is more than 2/rev, so there is no danger for ground resonance instability. This was confirmed by the fact, that during stability investigation the lead-lag motion of the blade was negligible. Anyway a ground resonance was the subject of the separate study (not reviewed here) including prospective helicopter fuselage degrees of freedom.

For stability evaluation rotor motion was investigated for helicopter full speed range i.e. for advance ratio up to 0.3. The rotor parameters taken to calculations are the base values given in Table II.

No symptoms of instability are encountered.

As an sample of results, in Fig.3. the rotor motion in flap hinge is presented in function of time for the first rotations. Each curve correspond to one advance ratio. Wind-tunnel trim is considered, as there is no cyclic pitch and the collective pitch is constant 10^0.

In the next set of plots in Fig.4 for the case of steady motion the amplitudes (i.e. the difference between the maximal and minimal values) of the rotor and the blade degrees of freedom are presented. The cases considered correspond to different values of hub stiffness, precone angles and blade droop. The values of amplitudes obtained are within reasonable limits. The values obtained for the selected hub variant are shown with solid line.

Concept development

There are still subjects to be addressed during the further studies.

To increase safety of operation, a spring failure indicator can be implemented as one sheet in the pack which would fail first before the others and this fact is reported to the pilot.

There are also some suggestions for extending utilisation of the concept such as controlled stiffness („smart") spring or utilisation of one rotor as extended „Hiller" type stabiliser.

Summary

A new see-saw rotor hub concept (which is now the subject of patenting process) has been developed and its applicability to light weight helicopter has been evaluated. The rotor motion analysis has not reveal any symptoms of instability. and showed the proper rotor operation within the flight velocity range of prospective light helicopter.

References

1. Rozhdestvensky M.G., „Scissors rotor concept: New Results Obtained", 52nd American Helicopter Forum Proceedings, Washington D.C., 1996.
2. Narkiewicz J., Łucjanek W., "Simulation of Helicopter See-Saw Rotor Motion", Pap. No. ERF 91-11, XVII European Rotorcraft Forum, Berlin 1991, Germany.

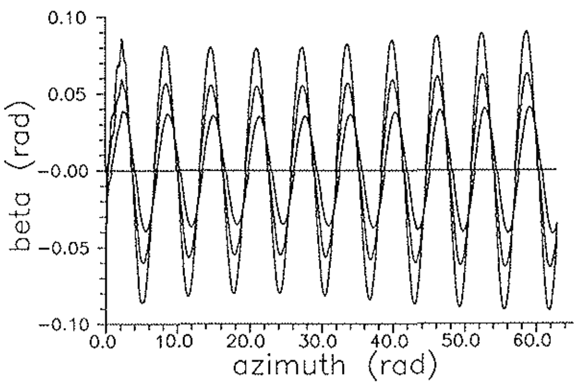

Fig.3. Blade flapping angle for base configuration; advance ratios: 0.0, 0.1, 0.2, 0.3.

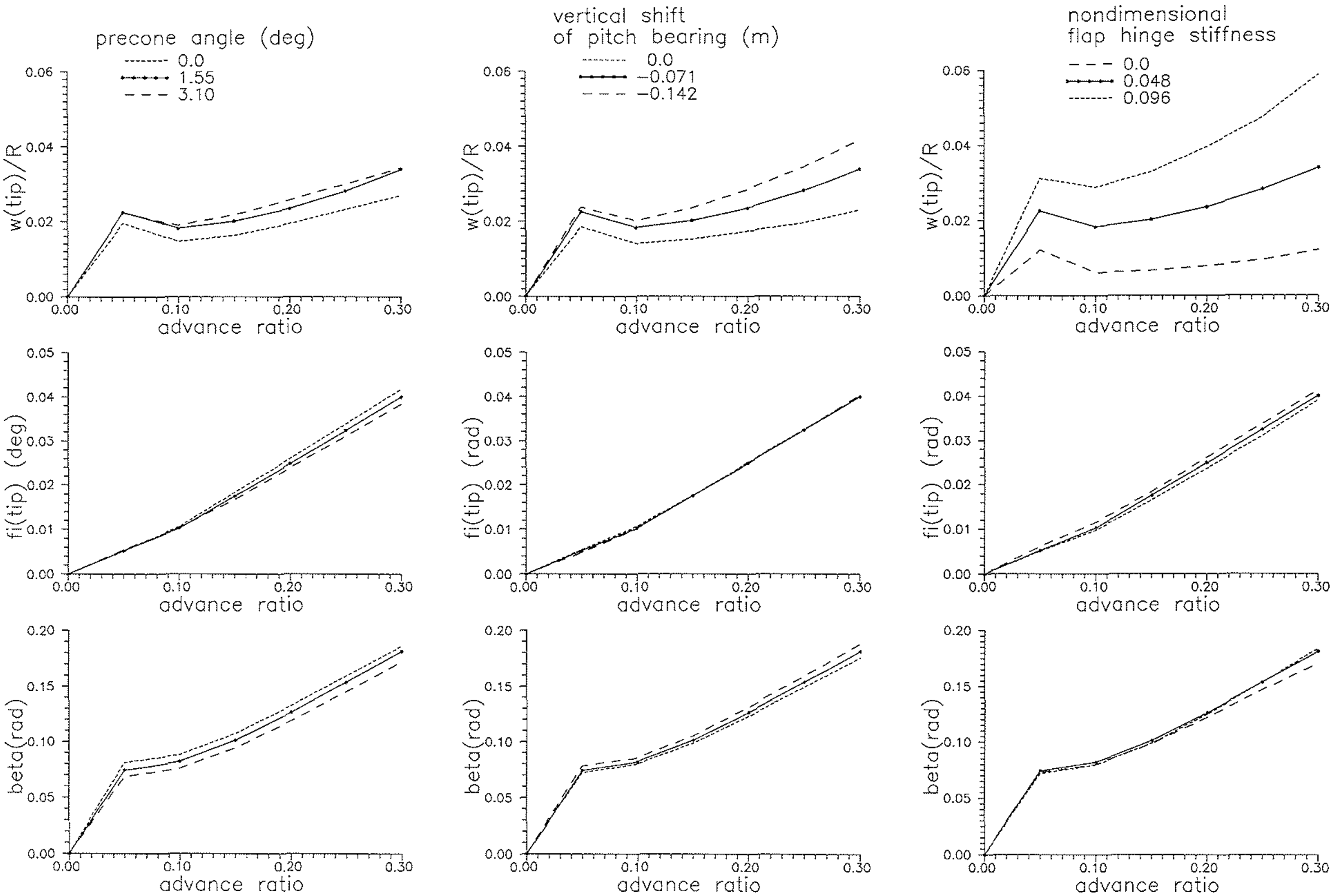

Fig.4. Influence of design parameters on amplitudes of rotor/blade motion.