EAN 2014
52nd conference on experimental stress analysis

Peculiarities of Computer Designing of the Rotors with Variable Parameters in Dynamics of Various Purposes

TURMANIDZE Raul[1,a]

[1]Georgian Technical University, Kostava str. 77, 0175 Tbilisi, Georgia

[a]inform@gtu.ge

Keywords: Rotor, variable geometry parameters blade, setting angle, twist, compensation of centrifugal forces.

Abstract. In the report the dynamics of perfection of the design of rotors with variable parameters at the Georgian Technical University during the last 15 years will be shown. All the positive and negative moments of each design have been analyzed and the effectiveness of use of such designs in aviation and wind energy installations have been validated.

Overview of the Problem

One of the promising directions in development of the optimal rotors is a creation of rotors with variable geometry parameters (VGR), namely the variable diameter of rotor and twist of blades.

At present mainly are used the rotors of fixed pitch (RFP) which are the result of non-optimal compromise between the requirements of hover mode and high cruise speed of flight. These rotors do not solve the optimization problem of all the flight stages; takeoff-cruise flight-landing. It was clear that there was a necessity of creation of the VGR for optimization of the all flight stages.

The VGR is effective both for helicopters and airplanes. However, there are bases to suppose that the VGR will be especially effective for propeller driven airplanes with vertical takeoff and landing (VTOL) as this aircraft works both in the vertical takeoff mode and cruise flight mode. The VGR can enable essentially to increase the payload or increase the cruise speed providing the maximum diameter and minimum twist in hover mode and contrary minimum diameter and maximum twist during cruise flight [1,2].

Despite a lot of works of well-known companies and scientists of various countries the VGR problem has not been solved yet. There are patents that did not find a real embodiment mainly because of complexity and insufficient reliability of technical solutions.

On must take into account that all the companies were engaged in change of some one parameter, for example, Sikorsky was busy with a change only of the rotor diameter and the Boeing was busy only with the twist of blades.

Georgian Technical University (GTU) suggested a combination of the diameter and twist changes during flight.

Through the International Science and Technology Center (ISTC) a team of specialists of GTU worked on Project G-060-2 “Variable Geometry Rotor (VGR) and Its Control Means (Actuators)”.

Initially at the analysis stage on the basis of extension of the object of investigations a model of the rotor with variable diameter was designed and manufactured and a model of the rotor with the variable twist of blades. After the laboratory tests of their basic units at the stage of synthesis was created the rotor with simultaneous variable diameter and twist of blades and also the stand for its tests [3].

The conducted stand tests of the VGR model have shown that at high rotational speeds arise considerable centrifugal forces acting on the jack-screw. The jack-screw is the most loaded element of the rotor design and is a weak unit. Reduction of the harmful influences of these forces became rather actual problem. Accordingly through the ISTC the GTU team of specialists worked on Project G-916 "Controlled Variable Geometry Rotor with Compensation of Centrifugal Forces".

The objective of the Project G-916 was the elaboration of the compensation system of centrifugal forces. The Technical Approach was in conduct of a model experiment in which the stand was stationary fixed in place. During rotation of the rotor in the fan mode were implemented measurements of the thrust depending on the change of the rotational speed and rotor diameter. This imitates conditions of the hover mode of the aircraft. From the possible compensation principles (mechanical, electrical, hydraulic) was chosen hydraulic as the most flexible in control [4,5].

For the design of this version of the VGR a European Patent has been received Application No/Patent No 08737551.5 - 2422 PCT/IB2008001041. At present it is being patented in the USA. All the financial costs were assumed by the European Union.

The security of dynamic tests of the VGR was provided by the reliability of units of the VGR with the system of compensation. For estimation of the reliability was designed and manufactured the stand of static tests on which experimentally were imitated the loads acting at various rotational speeds of the rotor. The elasticity lines of blade were determined depending on imitating rotational speeds at the retracted and extended blade and also dependence of forces on the control lever of the stand from the imitated rotational speeds.

The experiments on the stand for dynamic tests were conducted by the measuring method of the air flow speed with a revolving-vane analyzer which for this task was characterized with a sufficient iteration of measuring results.

It has been established that in case of increase of the rotor diameter 1.4 times and the change of the blade twist within $16 \div 18^0$ the increase of the thrust force is provided approximately 1.6 times.

The effectiveness of the compensation system is proved by multiple retraction-extension of the rotor blade in the all range of change of the rotational speed. It conditioned the synchronism of the VGR functioning.

Results of the works on the both Projects were reported and approved at the authoritative international scientific-technical conferences, patented and published in scientific articles. In Georgia and in Romania a monograph in Russian and English has been published.

New Design of the Rotor and Results of Its Tests

By the Collaborators of the Project has been proposed that for subsequent increase of effectiveness of use of the VGR, especially for small planes, it is expedient to simplify the mechanism of the diameter change and increase of the change range of twist of blades to $30 \div 35^0$.

The Project team suggested several design versions of solution to this task. The ISTC on the basis of support of the Collaborators has funded this proposal. From suggested design versions on the basis of consultations with the Collaborators and also with other competent specialists working in the field of aviation was chosen more optimal and in conditions of Georgia more realizable version. The essence of this version is the fact that the hub and blades are freed from any extra parts and units and only the rope remains the ends of which are fixed on the movable parts of blades. The blade itself with the free implementation of twist consists of flexible elements which are fixed between ribs (Fig. 1).

At the increase of the rotor rotations at the expense of arisen centrifugal forces the movable parts of blades are extended and the rotor diameter increases. For reduction of diameter the piston and rod of the hydro-cylinder travel in the necessary direction and by means of the ropes the rotor diameter decreases.

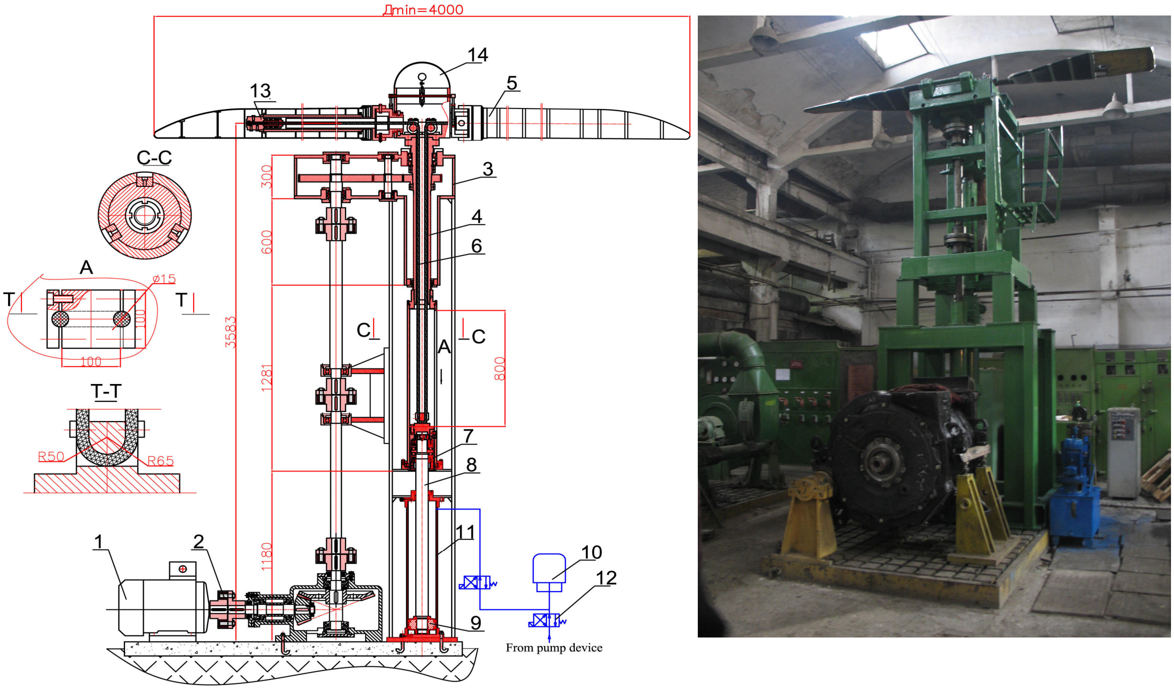


Fig. 1. Stand for dynamic tests.

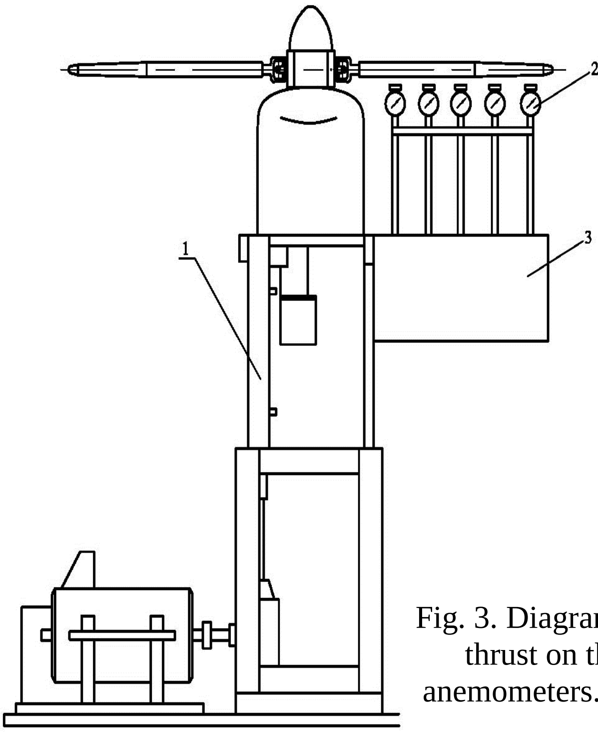
At the increase or decrease of the diameter by means of special mechanisms each rib every moment occupies preliminarily calculated angular position around the immovable spar by which is provided the maximum twist of blades at the minimum diameter and, contrary, minimum twist at maximum rotor diameter. By the same mechanisms of twist is kept the stability of shape of blades during rotation of the rotor i.e. during action of centrifugal and lift forces on blades.

Fig. 2. Blade with flexible elements and rib.

For this design was received the Georgian Patent and documents for a European Patent are being prepared for funding of which is the consent of the management of European Union.

During the first year according to the Work Plan was conducted a detailed analysis of the existing literary data, were implemented the necessary aerodynamic and strength calculations, were compiled technological maps of manufacturing all the significant parts, simultaneously were manufactured parts and units, was implemented updating of stands for static and dynamic investigations in accordance with the new rotor design, were conducted preliminary tests of blades on the stand for static tests and prepared the stand for dynamic tests for conduct of detailed experiments (Fig. 2).

By the elaborated method in the previous Project is measured the air flow speed in different sections of blades by the scheme shown in Fig. 3 and by means of well-known dependences are determined the character of distribution of the lifts along blades at various diameters of the rotor and values of the blades twist (Figs. 4 and 5).



Revolving-vane analyzer ACO-3

Fig. 3. Diagram of the installation for measuring of the rotor thrust on the stand by measuring speeds by means of anemometers. 1-VGR stand, 2–Anemometers, 3–Frame for setting anemometers.

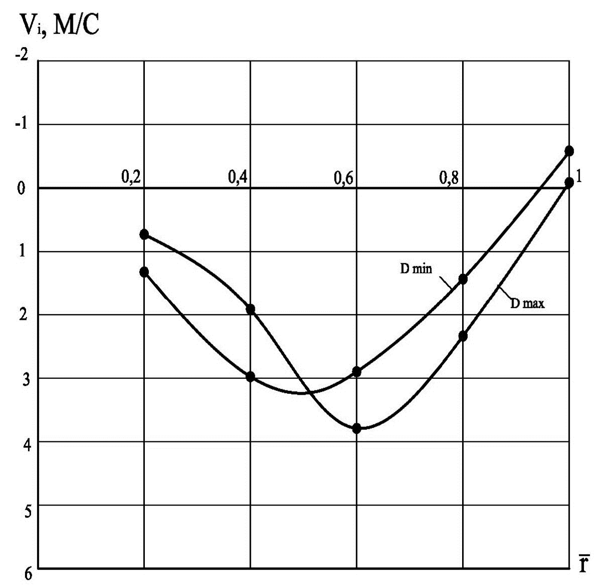


Fig. 4. Diagram of distribution of induced speeds along the blade span for different diameters of the rotor.

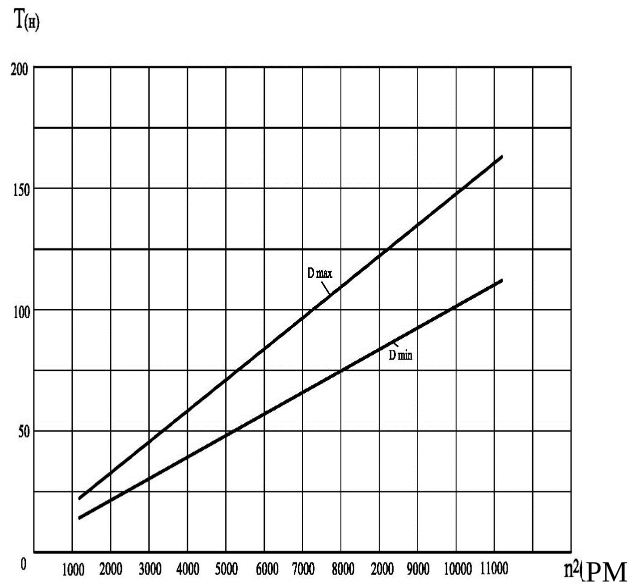


Fig. 5. Diagram of dependence of the VGR thrust from rotor rotational speed for case of the blade setting angle $\varphi_{0,75}=15^0$.

The influence of the blade setting angle on the value and character of distribution of the lift along the blade span have been studied. The results of some experiments are shown in Figs. 6, 7, 8, and 9.

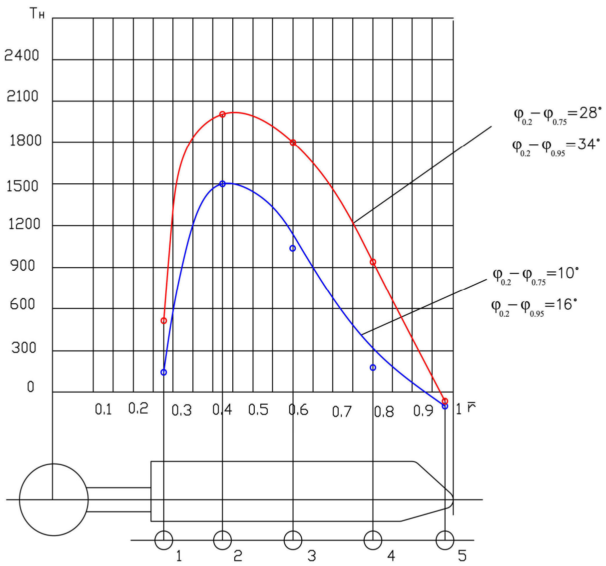


Fig. 6. Dependence of the VGR thrust from the blades twist change for the minimal diameter $D_{\min}$ of the rotor, rotational speed $n = 300$ RPM and setting angle $\varphi = 5^0$.

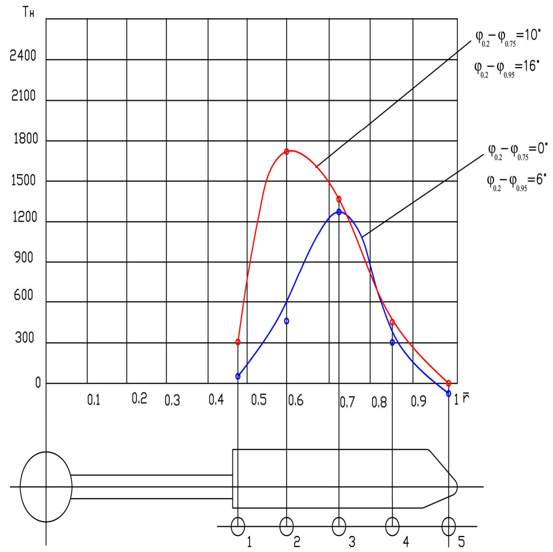


Fig. 7. Diagram of dependence of the VGR thrust from the blades twist change for the maximal diameter $D_{\max}$ of the rotor, rotational speed $n = 200$ RPM and setting angle $\varphi = 5^0$.

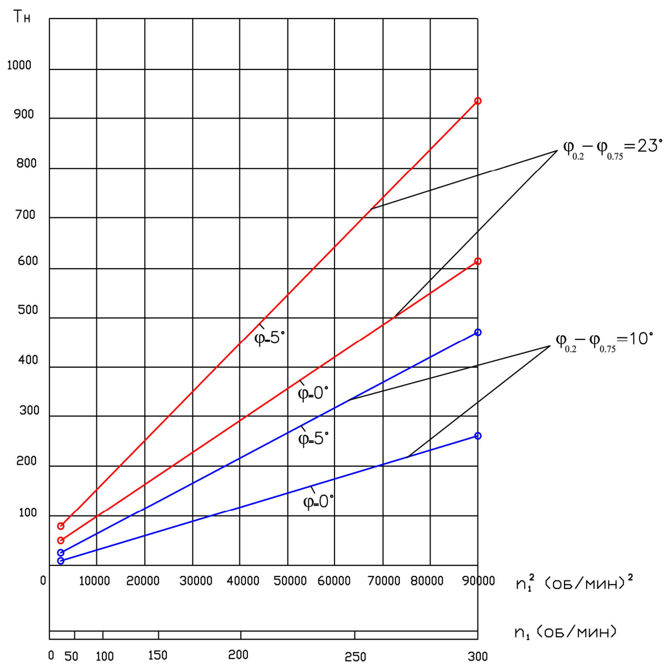


Fig. 8. Diagram of dependence of the VGR thrust from the rotor rotational speed for the minimal diameter $D_{\min}$.

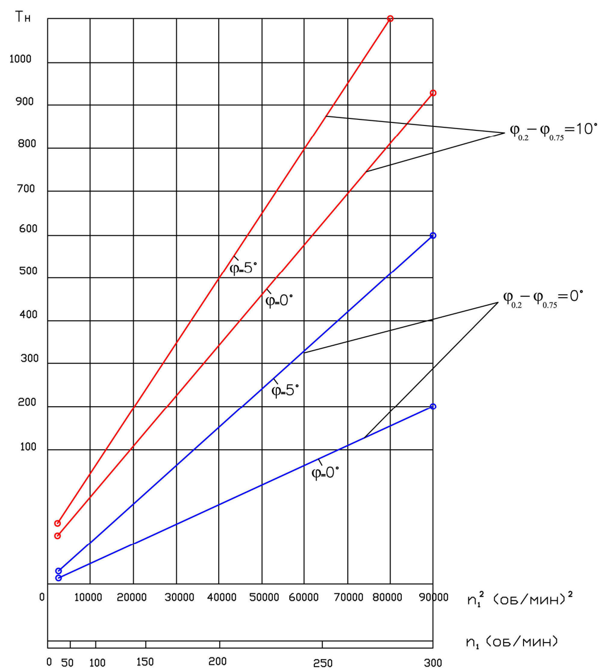


Fig. 9. Diagram of dependence of the VGR thrust from the rotor rotational speed for the maximal diameter $D_{\min}$.

A promotional clip has been prepared showing the consequence of the assemblage process of separate significant units and also the principle of their work both in animation mode and on the real rotor design and the stand for dynamic tests.

At present the specific calculations of the effectiveness of use of the elaborated designs are being conducted for wind-driven plants, dirigibles with high payload and propeller-screws of airplanes.

Conclusions

1. The developed rotor design with flexible elements enables to adjust the twist of blades in the given range (to $28^0 \div 30^0$).
2. The maximum values of the air flow speed in the rotor rotational flat at the low values of the twist corresponds to the radius $\bar{r} = 0.7,$ after the increase of the blades twist the value of maximum speeds insignificantly travel to the rotor center that reduces the radius of maximum loads and accordingly increases the rotor efficiency at the expense of decrease of the consumed power.
3. The created design enables to produce the blades twist practically along the whole length of the blade at observation of the optimal sizes of flexible elements.
4. There is a dependence of the thrust from the change of the VGR blades twist that enables to establish the optimal value of the twist for acquisition of the necessary lift.
5. The use of rotors of a new design on airplanes of VTOL can increase the payload approximately 1.6 times or distinctly increase the flight distance at the expense of reduction of the fuel consumption. The average approximate value of the increase coefficient of the flight distance is equal to 1.4 and the specific value will be determined in each specific case depending on the flight modes.

References

[1] V. Kharitonov, Autonomous Wind Power Installations, State Scientific Department “All Russian Scientific Research Institute of Electrification of Agriculture”, Moscow, 2006.

[2] R. Janson, Wind Installations, The Bauman HSTU Publishing House, Moscow, 2007.

[3] T. Al-Shemmeri, Wind Turbines, Bookboon.com (Ventus Publishing ApS), 2010.

[4] V. Animitsa, V. Golovin, M. Krainov, V. Novak, N. Tarasov, V. Shcheglova, Experiment-Calculated Investigations of Fields of Inductive Velocities Behind the Rotor on Aerodynamic Characteristics of the Antitorque Rotor at Small Flight Speeds at Lateral Wind, in: Proceedings of the 4th Forum of the Russian Helicopter Society, TSAGI, Moscow, 2004.

[5] R.S. Turmanidze, L. Dadone, J.J. Philippe, B. Demaret, Investigation, Development and Tests Results of the Variable Geometry Rotor, in: Proceedings of the 33rd European Rotorcraft Forum, Kazan, 2007, pp. 1158-1198.

[6] L. Dadone, J. Liu, J. Wilkerson, C.W. Acree, Proprotor Design Issues for High Speed Tiltrotors, in: Proceedings of the American Helicopter Society 50th Annual Forum, Washington, DC, 1994.