Acta Polytechnica **64**(1):12–17, 2024
https://doi.org/10.14311/AP.2024.64.0012

REDUCTION OF TORQUE PULSATION IN ULTRALIGHT HELICOPTER TRANSMISSION

Vitaly Dudnik[a, b]

[a] *Silesian University of Technology, Faculty of Mechanical Engineering, Akademicka Str. 2A, 44-100 Gliwice, Poland*

[b] *RS Helikopter GmbH, Design Department, Brienner Str. 7, D-80333 München, Germany*

correspondence: vvdudnik812@gmail.com

Abstract. Usually, 1–2 seats helicopters use piston engines. One of their disadvantages is a significant torque pulsation on the engine shaft. The main reason for such fluctuations is the change in parameters during the engine's operating cycle. The purpose of the investigation was to define the pulsation on the helicopter rotor shaft. An additional elastic clutch was used on a single-seat ultralight helicopter Rotorschmiede VA-115 of German firm RS Helikopter GmbH for pulsation dampening. Several flights were performed to assess the pulsation on the shafts. The results of the tests showed that the torque pulsation on the shaft in all modes does not exceed 30 %. This is 10 times less than the pulsation value of 300 % specified by the airworthiness standards for this helicopter class.

Keywords: Ultralight helicopter, piston engine, torque pulsation.

1. Introduction

In recent years light, very light, and ultralight helicopters have become widespread among the smallest rotary-wing aircraft in the world. As a rule, helicopters less than 2 tons of maximum take-off weight use piston engines. One of their disadvantages is a significant torque pulsation on the engine shaft. Generally, the trend in the development of aircraft engines is aimed at increasing the specific power, which also leads to an increase in the amplitude of engine torque fluctuations. In addition, lightening and reducing the inertia of moving parts, and accordingly, the rigidity of the transmission elements leads to a decrease in the effect of smoothing engine torque fluctuations. This phenomenon is most noticeable in modern four-stroke engines. The purpose of the research was to determine the piston engine pulsation and the possibility of reducing it in the transmission of an ultralight helicopter. To do this, several phenomena affecting such unevenness should be considered.

2. Torque pulsation on the engine shaft

The traditional methods of reducing engine torque variance are to increase the number of cylinders and ensure that the spark ignition in the cylinder alternates evenly. At the same time, an increase in the number of cylinders leads to a significant increase in engine weight. Modern internal combustion engines for general aviation are characterised by a relatively simple design with a flat and mirror-symmetric knee arrangement and a satisfactory balance of inertial forces. However, this does not always ensure small torque irregularity. The instantaneous value of the torque can change to a considerable extent during the stable operating mode of the piston engine, even when the load and the average speed of the crankshaft do not change per shaft revolution. Such fluctuations affect the increase in dynamic loads in the transmission, thereby decreasing the established time of helicopter parts. The main reason for such fluctuations is the change in parameters during the engine's operating cycle. In a two-stroke engine, the number of working strokes per revolution of the engine shaft is greater resulting in lower torque pulsation. The number of cylinders has a great influence on the amplitude of the engine oscillations. According to experiments, a 6-cylinder four-stroke engine has an oscillation amplitude three times lower than a four-cylinder engine with the same cylinders [1].

The pulsation of the torque of the motor shaft is estimated using the unevenness coefficient

$$\mu = \frac{T_{max} - T_{min}}{T_a}, \tag{1}$$

where

- T_{max} - maximal torque during one revolution,
- T_{min} - minimal torque during one revolution,
- T_a average torque.

Measurements made on the "Bumblebee' biplane aircraft showed that for a four-stroke, four-cylinder engine (Figure 1), even behind the gearbox, pulsations can reach high values, with a coefficient of unevenness ($\mu \geqslant 1$).

The influence of pulsation has to be taken into account during the design process of a rotary-wing aircraft. The pulsation rates are established in the airworthiness certification specifications. For example,

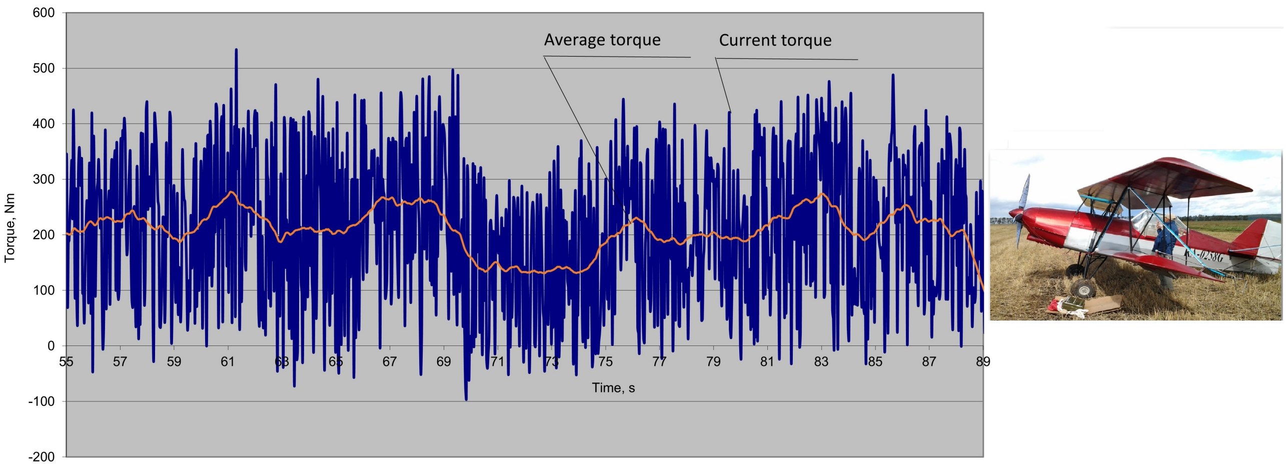


Figure 1. Recording of the torque pulsation on the rotor shaft of a biplane aircraft.

the following requirements are established for very light helicopters [2]:

"The limit torque may not be less than the mean torque for maximum continuous power multiplied by-

(1) For four-stroke engines-

(i) 1.33, for engines with five or more cylinders; and

(ii) 2, 3, 4 or 8, for engines with four, three, two or one cylinder, respectively.

(2) For two-stroke engines-

(i) 2 for engines with three or more cylinders,

(ii) 3, or 6, for engines with two or one cylinders, respectively."

Thus, it can be seen that the torque in the calculations for the strength of aircraft structures can be increased up to 8 times. Similar requirements are also set for lighter and heavier rotorcraft [3, 4]. In addition, it should be noted that the requirement of a safety factor of 1.5, established in paragraph 303 of all airworthiness standards, also applies to torque. It is obvious that if, when calculating the rotor system of a helicopter, it is not possible to take the indicators specified in the norms, the gearbox, hub, and shafts could be increased in weight to extreme values. Manufacturers of small helicopters take measures to reduce torque pulsation avoiding huge weight gains. Usually, rubber belts are used in the transmission for lighter rotorcraft. However, belts are designed to transmit significant power, so their significant rigidity does not allow them to effectively deal with pulsations. It is advisable to use additional dampening devices [5]. Some engines, for example, the MWfly series, incorporate a reactive vibration damper into the engine structure [6].

An additional elastic clutch was used in a single-seat ultralight helicopter Rotorschmiede VA-115 Rotorschmiede VA-115 of German firm RS Helikopter GmbH (Figure 2). It was installed between the engine and belt drive. This aircraft has a two-stroke two-cylinder engine with a maximal power of 50 hp.

Figure 2. Ultralight helicopter VA-115.

Taking into account the coefficients set by the requirements [3] for this aircraft and the safety factor, the estimated power of the transmission and carrier system should be increased 4.5 times and should be 225 hp. In fact, this is the power already used by 4-seat helicopters. The structure of the VA-115 helicopter transmission (Figure 3) includes a centrifugal clutch 2, mounted on the engine 1, a rubber elastic clutch 3, a rubber belt drive 4, a freewheel clutch 5 and a main gearbox 6.

Part of the pulsation is dampened in the gear engagement, which is immersed in oil, of course. This is a damper, but it allows you to decrease a sufficiently small amount that is insufficient for obtaining small pulsations on the main rotor shaft.

Rubber was chosen as the main material of the elastic coupling because it is a simple material, and has good damping properties and resistance to physical impacts. Of course, rubber materials have non-linearity in operation, but it is not critical for the operation of helicopter clutches. As can be seen in Figure 4, there are compressed and stretched zones. However, tension zones practically do not work, since the bearing capacity of rubber is five times higher in compression [7]. Several conditions must be met during the choice of a clutch from a rubber material. It should not have an

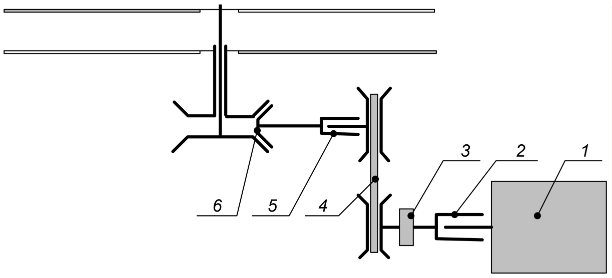


Figure 3. Scheme of the ultralight helicopter VA-115 transmission.

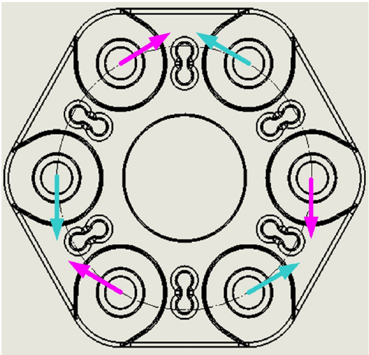


Figure 4. The direction of the forces on the rubber elastic clutch.

Figure 5. Coaxial rotor system of an ultralight helicopter with installed measuring modules.

excessive stiffness for effective damping. The condition of effective vibration isolation must be satisfied according to relation [8]:

$$\frac{\Omega}{\Omega_0} > \sqrt{2}, \tag{2}$$

where:

- Ω - working angular speed of the engine,
- Ω_0 - resonant angular speed of the system.

However, such a ratio may not be feasible under the conditions of ensuring the strength and reliability of aircraft structures. In terms of strength, the coupling must withstand the transmitted torque and significant centrifugal loads. First of all, the designer can provide the exact strength characteristics of the coupling.

3. Torque pulsation measurement results

A measuring system was used to perform measurements on board during flights (Figure 5). In flight tests, a challenge arises in transferring the measured data from the rotating rotor blade to the fixed airframe or saving them in the rotating part [9]. Despite the small size of the ultralight single-seat helicopter, the measuring system consisting of 3 parts was installed on the vehicle. The data were collected on hard drives mounted on the shafts. One performed measurements on the upper main rotor and rotated with it in one direction, the second on the lower rotor and rotated in the other direction, and the third was installed motionless on the fuselage. The loads were measured on various elements of the rotor system, including the shafts of the rotors. The moments on the shafts and their pulsation were measured by strain gauges assembled according to a bridge scheme. Strain gauges were fixed to the shafts at an angle of 45° to the shaft axis. The quality of the installation of sensors and measuring parameters was controlled by direct and reverse calibrations. The accuracy of the measuring system consisted of the accuracy of calibration, the accuracy of the measuring path, and the discreteness of the system set by software. The accuracy of the measuring path was determined according to the manual data of the measuring equipment. The calibration accuracy was assessed by the difference in measurements for reverse and direct calibrations. According to it, the total error in measuring the bending moment in the plane of rotation was 1.7 Nm for the upper rotor shaft and almost the same for the lower rotor shaft.

Several flights were performed to assess the pulsation on the shafts, including a minimum takeoff weight of 225 kg and a maximum of 270 kg. The engine was operated at or near the maximum power during the flights with maximum permissible weight. The flights were carried out in hover and horizontal motions. The evaluation was carried out at low, cruising, and maximum speed, as well as at some intermediate values in level flight. Sideways flights, turns, and sharp deceler-

Mode	Maximal pulsation of torque on upper rotor shaft with engine frequency ± %	Maximal pulsation of torque on lower rotor shaft with engine frequency ± %
Hovering (TOW - 270 kg)	17.8	28.4
Hovering (TOW - 225 kg)	13.4	24.4
Horizontal flight 100 km h^{-1} (TOW - 240 kg)	12.2	21.0
Horizontal flight 80 km h^{-1} (TOW - 240 kg)	9.1	18.3
Lateral flight (TOW - 240 kg)	10.8	19.9
Braking (TOW - 240 kg)	15.5	23.7

TABLE 1. Basic pulsation parameters in different flight modes.

ations in the air with a sharp change in pitch angle were also performed. An example of changing the torque parameters depending on the speed is shown in Appendix A.1. The data is presented from the engine start moment. Negative velocity values correspond to a hovering turn to the wind. From the presented dependencies, it can be seen that the absolute values of the pulsation on the shafts depend little on the magnitude of the transmitted torque. Since the required power drops sharply in a mode close to cruising, therefore, the relative magnitude of the oscillation becomes larger.

Pulsations on the helicopter shaft are possible from various factors and not only from the engine. However, the amplitude-frequency analysis shows that the torque pulsation occurs precisely at an engine operating frequency of about 100 Hz (Appendix A.2).

As tests have shown, a change in the take-off weight of the aircraft also does not seriously affect the magnitude of the pulsation. Appendix A.3 shows the values of torque pulsation on the shaft of the upper main rotor of a helicopter with different takeoff weights.

According to the test results, all values were summarised. Some pulsation parameters for different modes and different TOW (Take Off Weight) are shown in Table 1. The engine frequency varied within very small limits – 96–103 Hz during the test flights.

4. Conclusion

The results of tests performed on an ultralight single-seat helicopter showed that the pulsation on the shaft of the main rotor gearbox in all modes does not exceed 30 %. This is much lower than the pulsation value of 300 % specified by the airworthiness standards for this class of helicopters. This value was obtained due to the installation and selection of an effective elastic clutch in the transmission. Even though the clutch mainly provided the condition of strength and, as a result, had an increased rigidity, its efficiency turned out to be at a sufficient level. A tenfold decrease in pulsation compared to the standard values made it possible to reduce the extreme values of the torque in the transmission and obtain its low weight, and high aircraft performance.

References

[1] E. Savastenko, I. Nikishin, S. Devyanin. Reducing of the uneven torque level in the internal combustion engine. *Bulletin of RUDN Universityl* **74**(3):99–105, 2010. https://doi.org/10.1086/144770

[2] *Certification Specifications and Acceptable Means of Compliance for Very Light Rotorcraft, CS-VLR.* EASA, Cologne, 2018. 76 p. [2018-12-18]. https://www.easa.europa.eu/en/document-library/certification-specifications/cs-vlr-amendment-3

[3] *Bekanntmachung von Lufttüchtigkeitsforderungen für Ultraleichthubschrauber LTF – ULH.* DFS, Braunschweig, 2019. 61 p. [2019-02-28]. https://www.dulv.de/sites/default/files/Downloads/ltf%20ul-hubschrauber%202019-02-28%20nfl%202-460-19.pdf

[4] *Certification Specifications and Acceptable Means of Compliance for Small Rotorcraft CS-27.* EASA, Cologne, 2023. 321 p. [2023-02-07]. https://www.easa.europa.eu/en/document-library/certification-specifications/cs-27-amendment-10

[5] I. Stroe. Elastic and safety clutch with metallic roles and elastic rubber elements. *New Trends in Mechanism Science* **5**:285–292, 2010. https://doi.org/10.1007/978-90-481-9689-0_33

[6] MWfly Srl. [2021-03-01]. https://mwfly.it/en/motori_aeronautici/

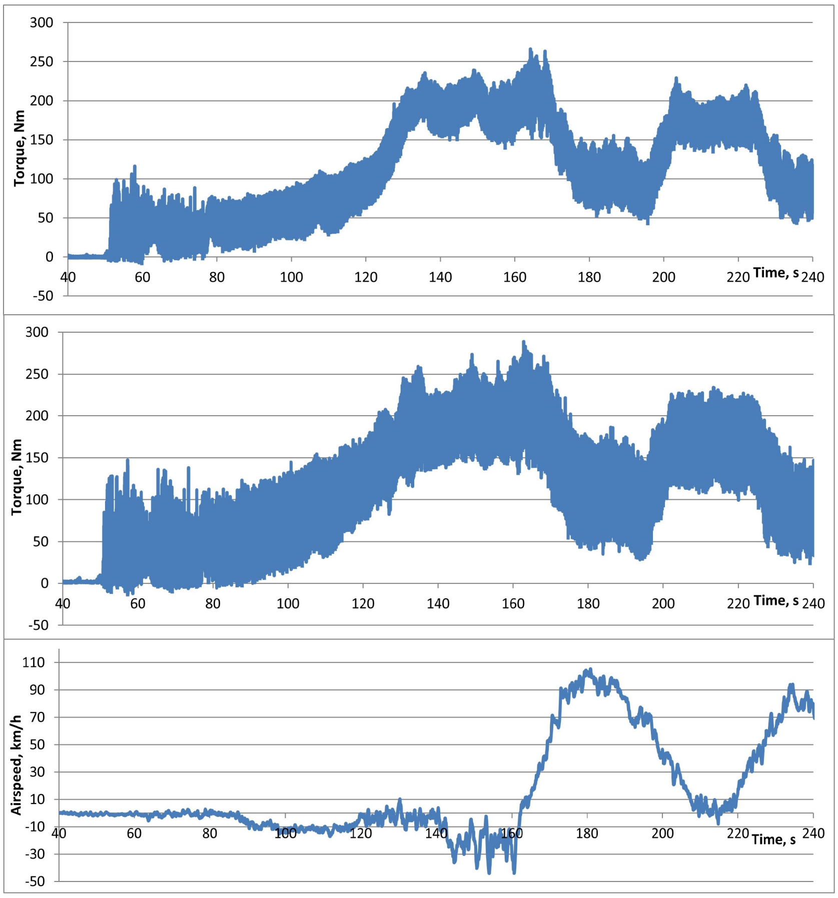
[7] L. Bushmarin, P. Dementiev, G. Ioffe. *Helicopter mechanical transmissions.* Mashinostroenie, Moscow, 1983. 185 p.

[8] *Vibration in Technical. Book 6.* Mashinostroenie, Moscow, 1981. 455 p.

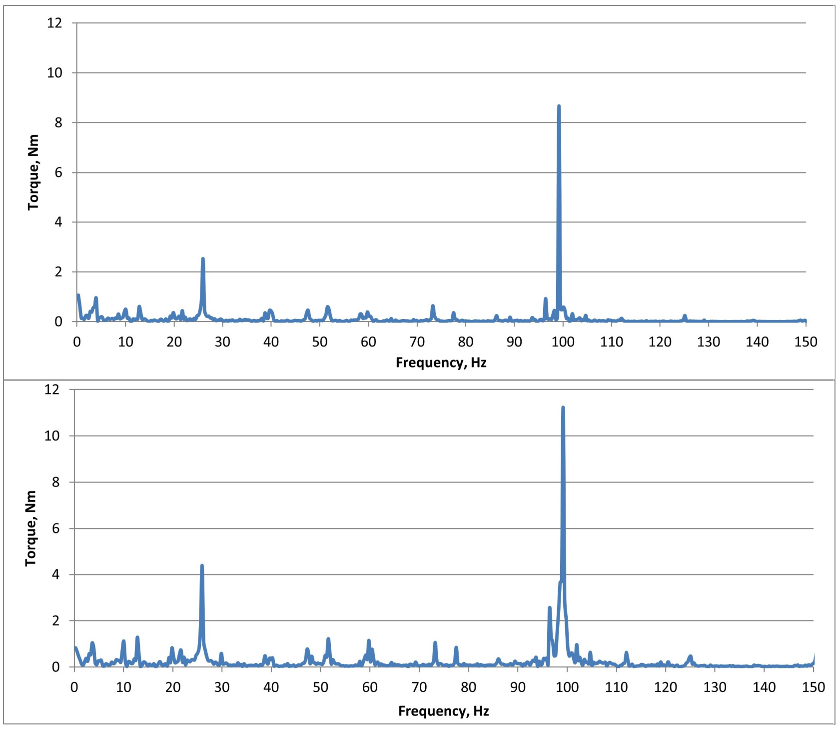
[9] H. Rapp, P. Wedemeyer, C. Teuberpresented. Measurement of in-flight rotor blade loads of an autogyro. pp. 100.1–100.8. 2000. [2016-06-30]. https://dspace-erf.nlr.nl/items/a6ef96c4-b131-4fdd-95ee-6dfb7d6ad90e

A. Appendices

A.1. Recorded torque on the shaft of the upper rotor (top), lower rotor (middle), and airspeed (bottom) during the hovering mode and horizontal flight.



A.2. Amplitudes of torque pulsation on the shafts of the upper rotor (top) and lower rotor (bottom) during the hovering mode



A.3. Recorded torque on the shaft of the upper rotor during the hovering mode, TOW - 225 kg (top) TOW - 270 kg (bottom).