Transmission diagnostics of single-rotor helicopters

Andrey Reshenkin[1], *Natalia* Kochkovaya[2*], and *Valerik* Ezdanyan[1]

[1] Don State Technical University, 1, Gagarina sq., Rostov-on-Don, 344002, Russia
[2] Institute of Technologies (branch) of Don State Technical University in Volgodonsk, 16, Mira str., Volgodonsk, 347386, Russia

Abstract. The usage of instrumental methods to monitor the technical condition of mechanisms leads to improved efficacy in detecting and warning of malfunctions. Timely detection of malfunctions during aircraft operation allows to avoid sudden failures and, as a consequence, to increase flight safety. Detection of defects is possible both during maintenance and by using inbuilt systems on board the aircraft. This paper proposes the method of instrumental monitoring of *tail shaft condition based on the Hall effect, following an* analysis of applied methods of transmission element diagnostics in single-rotor helicopters. The research outcomes permit us to suggest the development of various forms of selective and continual monitoring systems for the helicopter transmission condition, and advise for their implementation. Keywords: helicopter, diagnostics, Hall effect, tail shaft.

1 Introduction

The importance of addressing issues of improved reliability and efficiency regarding equipment components and technical systems is unquestionable. Within the aviation industry, this remains a key priority. The monitoring of technical conditions is directly related to human safety when it comes to aircraft. Due to the complexity of aircraft as technical systems, safety and reliability are of absolute importance [1].

In recent years, there has been significant progress in the diagnosis of faults in equipment, in keeping with the development of mechanical systems. The primary focus of research in this field is on four key areas: fault mechanisms, sensor and signal acquisition technologies, signal processing, and intelligent diagnostics [2]. It is worth mentioning that the implementation of non-contact technologies for acquiring and transmitting data regarding the state of the control object [3] represents a highly promising avenue with great potential.

* Corresponding author: kochkovaya@mail.ru

2 Materials and Methods

When operating helicopters, sometimes there is a problem associated with the deviation of the characteristics of the transmission operation from the mode parameters. This issue is prevalent in all mechanical systems that operate under static, cyclic, and shock loads, at both low and high temperatures, and in contact with diverse media.

Numerous studies have been conducted on the diagnosis of helicopter mechanical systems. Several studies explore the application of vibration and acoustic control [4-15]. In that context, the primary focus is the diagnosis of the main gearbox, transmission gearboxes, gearboxes, and other gear mechanisms. Several studies have presented solutions to wear problems through tribological diagnostics of components.

References [16, 17] provide insights into wear mitigation, while [18-25] offer further developments in fault modelling and analysis. Additional works have focused on mathematical modelling of fault occurrence processes and their analysis using various signal processing tools.

This paper considers one of the passive elements of the transmission of a single-rotor helicopter - the tail shaft.

The transmission's tail shaft is responsible for transmitting torque from the main gearbox through the intermediate and tail gearboxes to the tail rotor. The technical manuals for helicopter operation, specifically the single-rotor scheme, specify the requirement to check the condition of the tail shaft for the absence of torsion based on the straightness of the linear stripe applied onto the surface of the shaft sections. Non-linearity of the stripes (a sign of shaft tortional deformation) is not permitted [26].

Figure 1 shows the location of the shaft in the tail section of the helicopter and a fragment of it to illustrate the control stripes on the its surface.

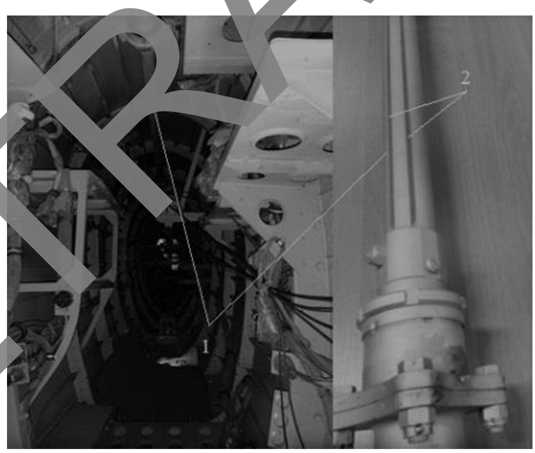

Fig. 1. Tail shaft (1), control stripes (2)

The design layout analysis of the tail components of the aircraft and the specified requirements pose doubts about the feasibility of conducting quality diagnostic work.

To enhance quantification, instrumental monitoring, and non-contact technologies may be utilized.

To acquire the essential information, using the Hall effect and its corresponding sensors is proposed.

An experimental setup was designed for the study, comprising a segment of the tail shaft (1), a KY-003 Hall sensor module (2), magnetic tokens (neodymium magnets measuring 6 mm in diameter and 3 mm in thickness) (3), a PS 1502DD laboratory power supply (4), an ISDS205A electronic USB oscilloscope (5), and an ICL laptop (6). Figure 2 depicts the setup.

The KY-003 module functions as a Hall sensor that is activated and deactivated by the presence of a magnetic field.

When a magnetic field is absent, the signal output contact maintains a logical value of (+5V). The value of the output is reversed (logical value of zero or 0V) when the Hall sensor is triggered by the presence of a magnetic field. [27].

Fig. 2. Experimental setup 1- fragment of tail shaft (1), 2 - Hall sensor module KY-003 (2), 3 - magnetic tokens (neodymium magnets with diameter of 6 mm and thickness of 3 mm) (3); 4 - laboratory power supply PS 1502DD (4); 5 - electronic USB oscilloscope ISDS205A (5); 6 – ICL laptop

Magnetic tokens attached to the surface of the tail shaft allow the the Hall sensor to be switched on and off when the tail shaft rotates, generating the signal recorded by the oscilloscope (Figure 3).

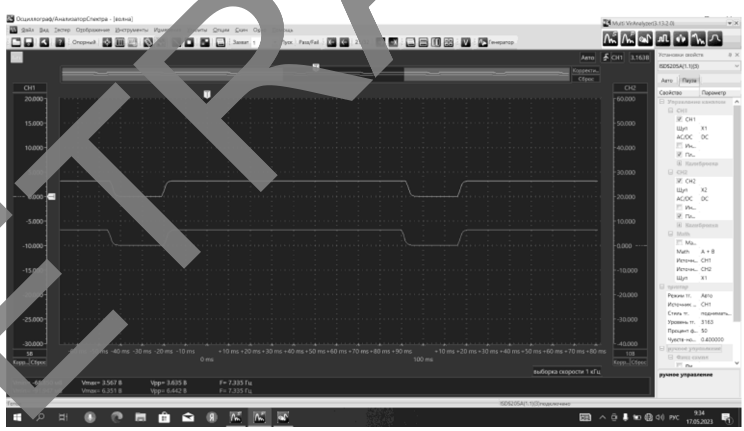

Fig. 3. Signal on the oscilloscope screen

In this instance, the registration of signals originates from two Hall sensors.

The occurrence of lateral movement (refer to Figure 4) defines the proceedings happening in the transmission of the helicopter while in operation.

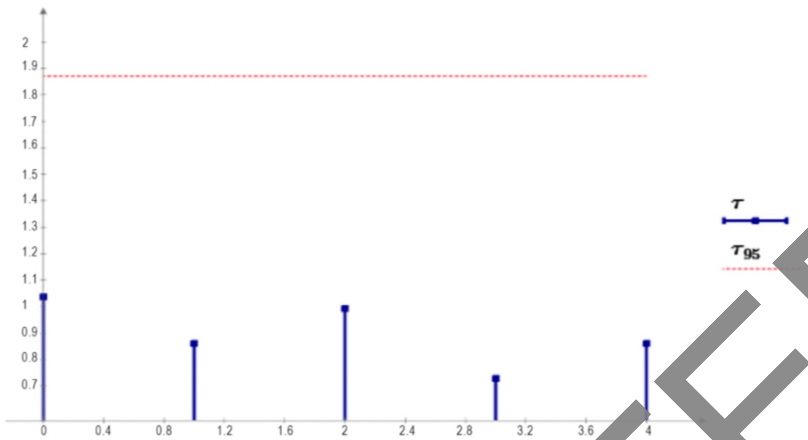

Fig. 4. Quantitative Analysis with the Tau-Criterion

The tau-criterion is used to identify critical levels of deformation at a 95% confidence level. Any values exceeding the set threshold, as indicated by the red line in Figure 4, are considered indications of deformation.

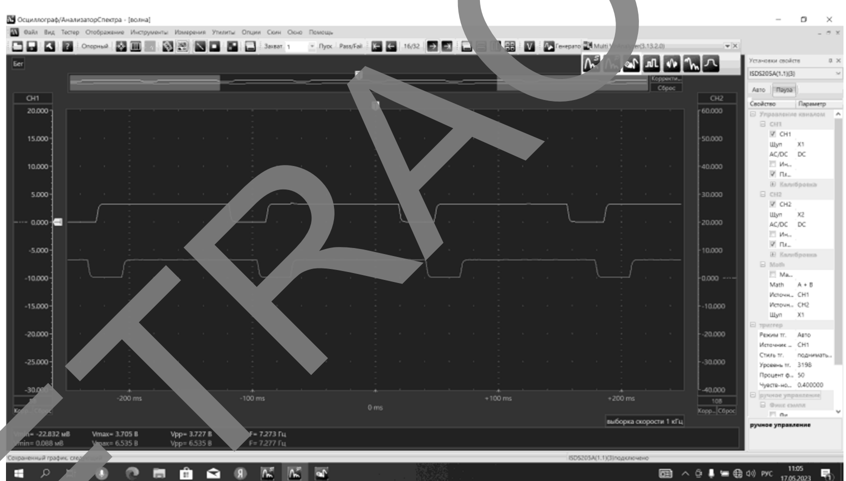

Fig. 5. Recording Hall sensor signal displacement caused by tail shaft torsion processes.

Based on conducted research, several types of selective and continuous control systems for monitoring the condition of helicopter transmissions can be developed.

For scheduled maintenance, a portable unit can be installed to monitor the tail shafts for torsion.

It is possible to install magnetic tags onto the shaft body and position stationary sensors on the helicopter to output information to a recording device via light signaling or in text format.

Supplementary information can then be acquired on the speed of rotation of tail shafts, failure of support bearings (wear or destruction resulting in increased load), and wear (destruction) of intermediate or tail gearboxes. Installation of more sensors is recommended depending on the number of tail shaft components available.

3 Conclusions

Thus, in conclusion, it should be noted that the possibility of timely detection of operational defects of aircraft structures can significantly increase their reliability and safety. The use of instrumental control (including in-built control) will have a positive impact on the airworthiness of the equipment in operation.

References

1. Abid, A., Khan, M.T. & Iqbal, J. Artif Intell Rev . **54**, 3639-3664 (2021). https://doi.org/10.1007/s10462-020-09934-2
2. Chen, X., Wang, S., Qiao, B. et al. Front. Mech. Eng. **13**, 264-291 (2018). https://doi.org/10.1007/s11465-018-0472-3
3. Worek, C., Krzak, Ł., Mrówka, R., Barszcz, T. (2018). *Comparison of Wireless Technologies for Rotating Machinery Diagnostics*. In: Timofiejczuk, A., Łazarz, B.E., Chaari, F., Burdzik, R. (eds) Advances in Technical Diagnostics. ICTD 2016. Applied Condition Monitoring, vol 10. Springer, Cham. https://doi.org/10.1007/978-3-319-62042-8_12
4. Kolesnikov, V.I., Koropets, P.A. & Sinyutin, E.S. Russ. Aeronaut. **63**, 7-13 (2020). https://doi.org/10.3103/S106879982001002X
5. Mironov, A., Doronkin, P., Priklonsky, A. (2018). *Advanced Vibration Diagnostics for Perspectives of Helicopter Technical Maintenance*. In: Kabashkin, I., Yatskiv, I., Prentkovskis, O. (eds) Reliability and Statistics in Transportation and Communication. RelStat 2017. Lecture Notes in Networks and Systems, **vol 36.** Springer, Cham. https://doi.org/10.1007/978-3-319-74454-4_13
6. Canfei SUN, Youren WANG, Guodong SUN, Chinese Journal of Aeronautics **33,** 5, 1549-1561 (2020), https://doi.org/10.1016/j.cja.2019.07.014.
7. R.B. Randall, Engineering Failure Analysis, **11**, 2, 177-190 (2004), https://doi.org/10.1016/j.engfailanal.2003.05.005.
8. Faris Elasha, Matthew Greaves, David Mba, CIRP, **59**, 111-115 (2017), https://doi.org/10.1016/j.procir.2016.09.030.
9. Andrzej Gębura, Sylwester Kłysz, Tomasz Tokarski, Procedia Structural Integrity, **16**, 184-191 (2019), Ihttps://doi.org/10.1016/j.prostr.2019.07.039.
10. L. Zhou, F. Duan, D. Mba, W. Wang, S. Ojolo, Engineering Failure Analysis, **92**, 71-83 (2018), https://doi.org/10.1016/j.engfailanal.2018.04.051.
11. Paul D. Samuel, Darryll J. Pines, Journal of Sound and Vibration **282**, 1–2, 475-508 (2005), https://doi.org/10.1016/j.jsv.2004.02.058.
12. Victor Girondin, Herve Morel, Jean-Philippe Cassar, Komi Midzodzi Pekpe, IFAC Proceedings Volumes, **45**, 20, 180-185 (2012), https://doi.org/10.3182/20120829-3-MX-2028.00050.
13. Aleksey Mironov, Pavel Doronkin, Aleksander Priklonsky, Igor Kabashkin, Procedia Engineering, **178**, 96-106 (2017), https://doi.org/10.1016/j.proeng.2017.01.070.
14. Linghao Zhou, Fang Duan, Michael Corsar, Faris Elasha, David Mba, Applied Acoustics **147**, 4-14 (2019), https://doi.org/10.1016/j.apacoust.2017.12.004.
15. Faris Elasha, Matthew Greaves, David Mba, Abdulmajid Addali, Procedia CIRP, Volume **38**, 30-36 (2015), https://doi.org/10.1016/j.procir.2015.08.042.

16. Vershinina, N.V., Boiko, M.V. (2021). *Tribological Diagnostics of the Mi-26 Helicopter Tail Transmission*. In: Radionov, A.A., Gasiyarov, V.R. (eds) Proceedings of the 6th International Conference on Industrial Engineering (ICIE 2020). ICIE 2021. Lecture Notes in Mechanical Engineering. Springer, Cham. https://doi.org/10.1007/978-3-030-54814-8_142
17. H.S.J. Rashid, C.S. Place, et.al., Reliability Engineering & System Safety **139**, 50-57 (2015), https://doi.org/10.1016/j.ress.2015.01.021.
18. Thomas P. Hamilton, Artificial Intelligence in Engineering, **3,** 3, 141-150 (1988) https://doi.org/10.1016/0954-1810(88)90030-1.
19. Pierre Bect, Zineb Simeu-Abazi, Pierre Lois Maisonneuve, Aerospace Science and Technology, **46**, 339-350 (2015), https://doi.org/10.1016/j.ast.2015.07.024.
20. H. Chin, K. Danai, D.G. Lewicki, Control Engineering Practice **1**, 5, 771-778 (1993) https://doi.org/10.1016/0967-0661(93)90243-K.
21. Paul D. Samuel, Darryll J. Pines, Journal of Sound and Vibration **319**, 1–2, 698-718 (2009) https://doi.org/10.1016/j.jsv.2008.06.018.
22. Jiao Hu, Niaoqing Hu, Yi Yang, Lun Zhang, Guoji Shen, Measurement, **198**, 111347 (2022) https://doi.org/10.1016/j.measurement.2022.111347.
23. H. Chin, K. Danai, D.G. Lewicki, IFAC Proceedings Volumes, **26**, 2, Part 2, 593-596 (1993) https://doi.org/10.1016/S1474-6670(17)49012-4.
24. Jessica Leoni, Mara Tanelli, Andrea Palman, Expert Systems with Applications **210**, 118412 (2022), https://doi.org/10.1016/j.eswa.2022.118412.
25. M. Zacksenhouse, S. Braun, M. Feldman, M. Sidahmed, Mechanical Systems and Signal Processing, **14**, Isue 4, 523-543 (2000), https://doi.org/10.1006/mssp.2000.1297.
26. MI-8 MT Helicopter Technical Operation Manual 8MT-007-00 RE-LU Power Plant, Book 4, Third Edition, (M: Airexport, 1979)
27. Hall sensor module KY-003 URL: https://rxtx.su/mikrokontrollery/arduino/moduli-i-datchiki-k-arduino/modul-datchika-xolla-ky-003/