http://dx.doi.org/10.35596/1729-7648-2026-24-3-85-91

UDC 004.5, 159.9:62

AN APPROACH TO TRANSFER OF CONTROL BETWEEN AUTOMATED VEHICLE AND DRIVER

VLADIMIR DUBOVSKY, VLADIMIR SAVCHENKO

The Joint Institute of Mechanical Engineering of the National Academy of Sciences of Belarus (Minsk, Republic of Belarus)

Abstract. In vehicles with level 3 automation, the driver can transfer control of the vehicle to the automated driving system without monitoring its operation. However, in critical situations or if the automated vehicle exits the normal operating domain, the driver must take control. In these cases, the driver may be unable to safely operate the vehicle due to insufficient awareness of the road situation and unpreparedness for the driving task. This problem is currently being addressed by monitoring the driver's condition and prompting them to take manual control using a multimodal interface. However, due to its complex, interdisciplinary nature, this problem has not yet been fully resolved. The aim of this study was to propose a new approach to mitigating safety risks during the transition from automated to manual driving. Based on an analysis of existing methods for solving this problem, a new approach is considered that takes into account the individual psychophysiological characteristics of the driver before transferring control of the vehicle. This approach provides greater flexibility, validity, and reliability of decision making in critical driving situations when switching between driving modes.

Keywords: automated cars, control transfer, human factors, human-machine interface, information technology, road safety, driving mode.

Conflict of interests. The authors declare that there is no conflict of interests.

For citation. Dubovsky V., Savchenko V. (2026) An Approach to Transfer of Control Between Automated Vehicle and Driver. *Doklady BGUIR*. 24 (3), 85–91. http://dx.doi.org/10.35596/1729-7648-2026-24-3-85-91.

ПОДХОД К СМЕНЕ РЕЖИМА ВОЖДЕНИЯ В АВТОМАТИЗИРОВАННОМ ТРАНСПОРТНОМ СРЕДСТВЕ

В. А. ДУБОВСКИЙ, В. В. САВЧЕНКО

Объединенный институт машиностроения Национальной академии наук Беларуси (Минск, Республика Беларусь)

Аннотация. В автомобилях с уровнем автоматизации 3 водитель может передать управление транспортным средством системе автоматизированного вождения и не контролировать ее работу, но в критических ситуациях или в случае выхода автоматизированного транспортного средства из домена штатной эксплуатации он должен взять управление в свои руки. В этих случаях водитель может оказаться не в состоянии безопасно управлять транспортным средством из-за недостаточной осведомленности о дорожной ситуации и неготовности к выполнению задачи вождения. В настоящее время эта проблема решается на основе мониторинга состояния водителя и выдачи ему соответствующего запроса на ручное вождение с использованием мультимодального интерфейса. Однако из-за сложного междисциплинарного характера эта проблема не решена окончательно. Цель исследования состояла в том, чтобы предложить новый подход к снижению рисков для безопасности при переходе от автоматизированного вождения к ручному. На основе анализа известных методов решения данной проблемы рассмотрен новый подход, который принимает во внимание индивидуальные психофизиологические качества водителя, прежде чем передать ему управление транспортным средством. Такой подход обеспечивает большую гибкость, обоснованность и надежность принятия решения в критических дорожных ситуациях при смене режима вождения.

Ключевые слова: автоматизированные автомобили, передача управления, взаимодействие водителя с автомобилем, человеко-машинный интерфейс, информационные технологии, безопасность дорожного движения, режим вождения.

Конфликт интересов. Авторы заявляют об отсутствии конфликта интересов.

Для цитирования. Дубовский, В. А. Подход к смене режима вождения в автоматизированном транспортном средстве / В. А. Дубовский, В. В. Савченко // Доклады БГУИР. 2026. Т. 24, № 3. С. 85–91. http://dx.doi.org/10.35596/1729-7648-2026-24-3-85-91.

Introduction

Currently, automotive vehicles evolve towards autonomous cars with fully automated driving systems (ADS) [1]. This process can be illustrated in a general way by the standard, SAE J 3016, developed by the Society of Automotive Engineers (SAE International) [2], which formally defines the levels of driving automation from 0 (no driving automation) to 5 (full driving automation). In accordance with this standard at level 1 the driver is in control of the vehicle and may be assisted in steering, accelerating or braking; at level 2 in specific driving conditions the longitudinal and lateral control of the vehicle is performed by the automation, but the driver must be engaged in the driving task at all times; at level 3 in specific driving conditions the vehicle is fully controlled by the ADS without any driver involvement, but the driver must be ready to take control of the vehicle at all times in case of the system failure; level 4 is similar to level 3, differing only in that the driver is not obliged to take control of the vehicle even in the case of a system failure, while the driver may have the option of controlling the vehicle.

Level 2 vehicles are already available on the market and level 3 vehicles are expected to be available shortly [3]. But in order for this to happen, the human factors issue of transfer of control between automated driving (AD) and manual driving (MD) must be solved in the most efficient and safe way. This issue is associated with driver complacency, lack of attention to the road, loss of situation awareness, sudden changes in workload, and degradation of driving skills and abilities due to the fact that the automated vehicles allow the drivers to be out of the control loop for extended periods but don't exclude resuming the manual control at any time [4]. The aforementioned factors can affect driver performance negatively since they could lead to a delayed and inadequate response of the driver during transitions between automated and manual vehicle control and therefore need to be carefully studied and properly taken into account in designing a control mode switching system for level 3 vehicles [1, 5].

Many research studies have been carried out on this topic to find the most efficient and safe methods for transferring vehicle control from AD to MD, however, due to the complex, interdisciplinary nature of this problem, it has not yet been finally solved [3]. In order to mitigate safety risks during driver take-over process, a good understanding of the current driver's state and the opportunities that exist for fast regaining of driver readiness to take back control is needed first of all [3].

An approach to a control transfer

A basic diagram of the transition of vehicle control between AD and MD is depicted in Fig. 1. This transition process includes four main stages: (1) driving conditions monitoring during AD for determining whether all necessary conditions for AD are satisfied or not; (2) take-over request (TOR) is issued by the ADS to the driver in emergency situations or when the conditions for AD are not met; (3) determining whether the driver is ready for MD based on a continuous monitoring of the driver state during AD; (4) control mode switching from AD to MD when the driver is ready for MD, otherwise, the ADS performs a minimum risk maneuver and stops the vehicle.

The level 3 automated vehicle should be able to detect its failures or when the specific conditions under which it is intended to drive in the automated mode are not met anymore. The necessary conditions for AD should be documented by the vehicle manufacturers in the operational design domain that should include the following information at a minimum: roadway types; geographic area; speed range; environmental conditions (weather as well as day/night time); and other domain constraints [6].

The TOR can be performed in the form of visual, auditory, or vibrotactile cues, or any combination thereof. The most common TOR design concepts are aimed at restoring the driver functional state and situational awareness as soon as possible in order to minimize the driver response time which depends on a number of factors such as traffic density, driver state, driving situation, road conditions, environmental conditions, TOR notification modalities and non-driving secondary task [3]. Therefore, TOR must be flexible and take the mentioned factors into account to be effective.

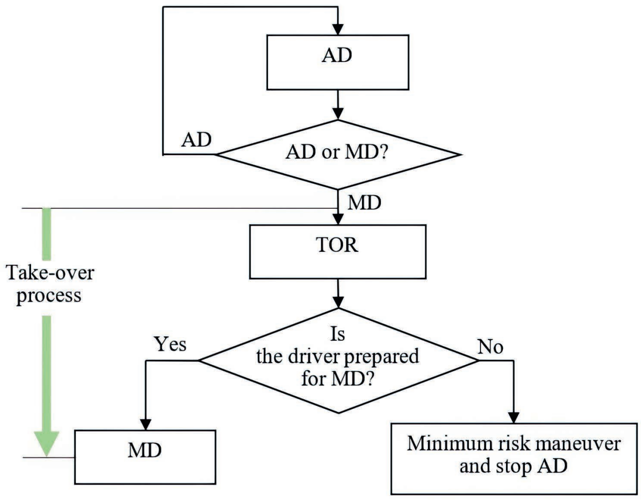

Fig. 1. A basic diagram of the transition of vehicle control between automated driving and manual driving

The driver readiness to take-over control of the vehicle is evaluated based on analysis of a driver's psychophysiological and behavioral data (eyes, head, and body movements, heart rate, electrodermal activity, and so on) combined with the data on the driving situation. In this regard, it is essential to recognize potentially dangerous driver states, such as distraction, fatigue, drowsiness, and other undesirable states that affect takeover performance negatively [3]. In accordance with the UNECE ALKS regulation [7], the driver readiness (availability) recognition system shall detect whether the driver is in an appropriate driving position and whether the driver's psychophysiological state (attention) is appropriate to the driving conditions. The driver's driving position is determined by monitoring the position of his/her trunk, head, hands/arms, and feet/legs based on video recording, pressure sensors embedded into driver's seat, steering touch and force sensors, seat position sensors, steering position sensors and the seatbelt buckle switch [4]. The driver's psychophysiological state is evaluated in terms of the presence and levels of abnormal states primarily such as drowsiness, distraction, and emotions (stress or anger) [8]. Various physiological and behavioral parameters are used as indicators of these abnormal states. In order to identify whether the driver is in a drowsy state and determine the level of drowsiness the indicators such as the brain activity (pattern of the electroencephalogram), heart activity (heart rate, and heart rate variability), breathing activity (breathing rate or inspiration-to-expiration ratio), electrodermal activity (skin conductance), pupil diameter instability (amplitude and frequency of the pupil diameter fluctuations), eye activity (eye movement analysis using electrooculography signals or video sequences of the eyes), and eye closure dynamics (percentage of closure, mean blink duration, mean blink frequency or interval, and eye closing and reopening speeds) can be used [8]. In order to identify whether the driver is in distraction and determine the level of distraction the indicators such as the driver's hands behavior (positions and movements), gaze activity (gaze direction, fixation duration, glance frequency, and gaze distribution), head behaviour (head pose and movements), brain activity (pattern of the electroencephalogram) are mostly used [8]. The main indicators used to detect the driver's negative emotions are the heart activity, electrodermal activity, breathing activity, brain activity, speech and facial expressions [8].

The control mode can be switched from AD to MD immediately and completely after the TOR is confirmed by the driver or gradually with increasing authority, depending on the driver state and the driving situation [7].

Thus, the primary task to be solved during the developing of methods for transferring control to the driver is to reduce the take-over time (the time between the TOR and the first measurable response to the situation [5], taking into account the requirements of safety, comfort, and quality of the take-over performance.

The immediate control transfers from automation to driver (Fig. 1) can be performed if the driver readiness (driver state and situation awareness) for MD at the moment of issuing the TOR is high enough for the required driving task. In this case the average take-over time may be around 3 seconds depending on the driver individual characteristics and driving circumstances [9].

If the driver readiness for MD does not meet the required level it is necessary to help the driver to increase his/her control capability to required level. For this purpose, the approach based on concept of driver-automation shared control (for instance through a haptic control interface) during take-over process is the most promising solution since it allows to allocate the execution of the driving task between automation and driver in accordance with the current driver state and driving situation until the driver state reaches the desired level and take-over is complete [4]. A basic diagram of the transition of vehicle control between AD and MD via shared authority mode, and conceptual diagram of the authority transfer method via shared authority mode are depicted in Fig. 2 and Fig. 3 respectively. In accordance with research literature the mean take-over time for shared control authority transition ranges from 0.69 to 19.79 s, depending on the different conditions [10].

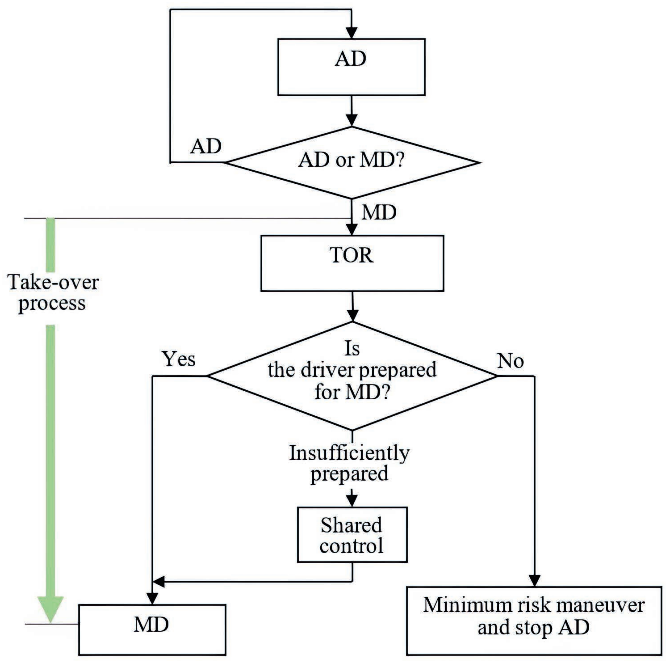

Fig. 2. A basic diagram of the transition of vehicle control
between automated driving and manual driving via shared authority mode

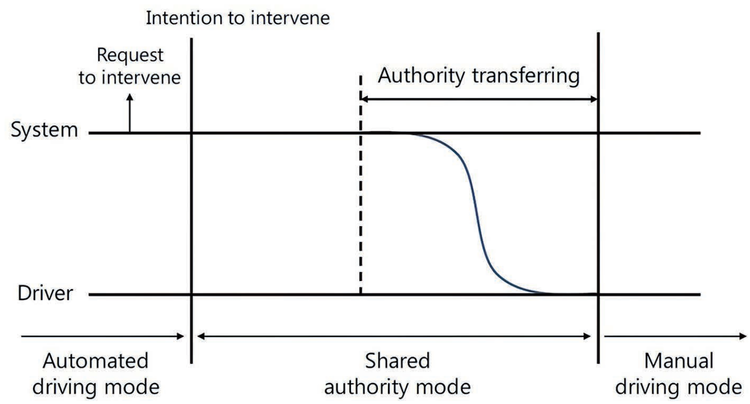

Fig. 3. A conceptual diagram of the authority transfer method via shared authority mode

Such an approach may help driver to take back control of a vehicle in a safe and smooth manner if the time budget (the time between the TOR and the moment when the vehicle would have reached the system boundary assuming no driver response [11]) allows to do it. But in critical situations when urgent take-over is required due to the ADS failure the shared control during authority transition can be risky. In such critical situations when the driver readiness for MD does not meet the required high level and is close to the minimum allowable value, the solutions that take into account the driver's ability to mobilize the required internal resources to meet the task demands are needed.

In addition, it should be noted that the existing research on this topic mainly focuses on characterizing the current state of the driver without prediction of his/her future behavior that can be affected by the intrinsic variability of human nature [8].

To overcome these shortcomings of existing research, we propose an approach to a control transfer that uses the driver's relatively stable individual psychophysiological characteristics as indicators (predictors) of his/her ability to mobilize the required internal resources for decision-making in critical situations during the transition from AD to MD.

The approach is based on collecting data on the driver's individual psychophysiological characteristics (IPC) such as motor reaction, ability to act urgently, concentration and distribution of attention, and so on, during periods of MD and using them for decision-making in critical take-over situations during AD. Such IPC of the driver are important for traffic safety, especially in critical situations, and must be taken into account as an additional risk factor during take-over process [12].

Two diagrams of the transition of vehicle control between AD and MD were developed in accordance with the proposed approach and are presented in Fig. 4 and Fig. 5. Fig. 4 shows the binary approach of shifting control entirely with taking into account the current driver's IPC and Fig. 5 shows a diagram that combines a shared authority mode with the decision-making based on the current driver's IPC information.

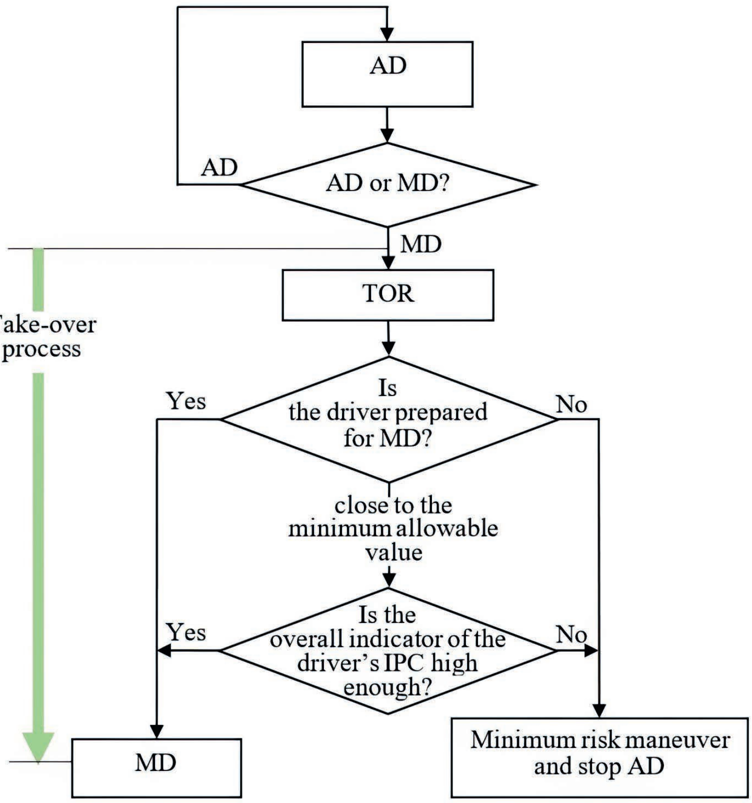

Fig. 4. A diagram of the immediate transition of vehicle control entirely with taking into account the current driver's IPC

In order to determine the overall value of the driver's IPC the indicators of various IPC of the driver should be determined based on monitoring of the vehicle, driver, and environment states during MD. Such psychophysiological characteristics as reaction time, ability to act urgently, vigilance, concentration and distribution of attention, perception of speed and distance, and risk propensity during MD are essential for this purpose. One way to determine the numerical values of indicators of such IPC can be implemented by using a collision avoidance system, which allows to detect the unintentional deviation from the driving lane, unsafe distance from the vehicle ahead, potential collision with a pedestrian in front of the vehicle, and speed limit signs along the road. To ensure the reliability of the IPC assessment, the necessary data must be recorded only in cases when the weather conditions are favorable for driving.

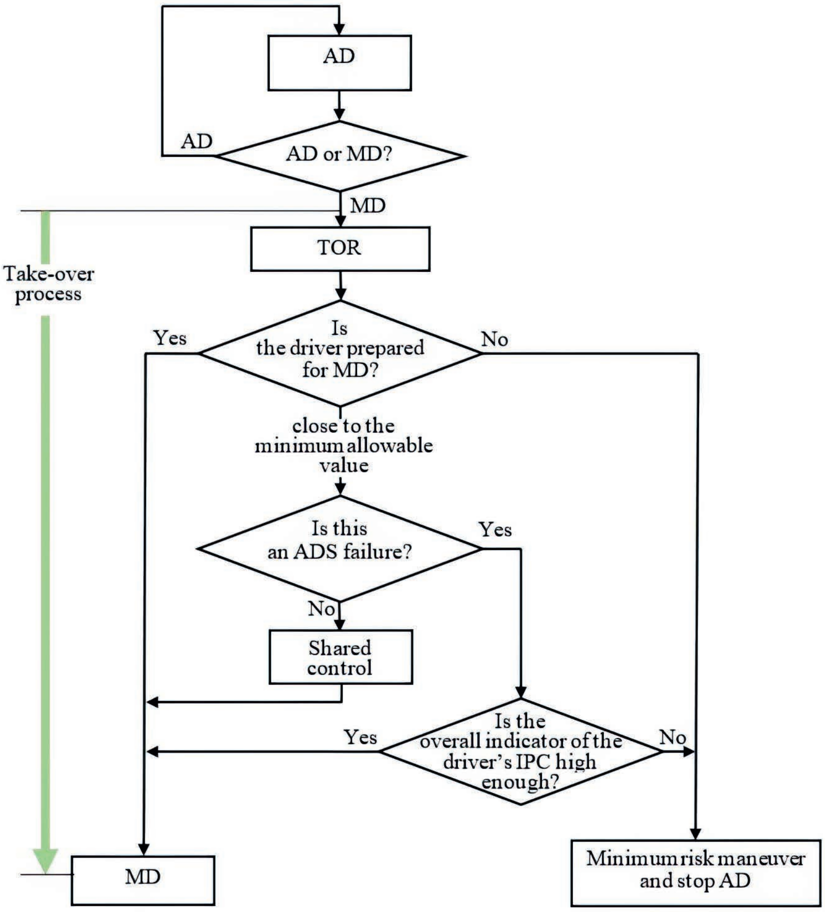

Fig. 5. A diagram of the transition of vehicle control between AD and MD using shared authority mode, or decision-making based on the current driver's IPC information

Conclusion

In this paper, we propose a new approach to transfer control from automated vehicle to a human driver based on the use of information about driver's individual psychophysiological characteristics during decision-making in critical situations to mitigate safety risks. The approach involves collecting data on the driver's individual psychophysiological characteristics such as motor reaction, ability to act urgently, concentration and distribution of attention, and so on, during periods of manual driving and using them in critical take-over situations during automated driving. This approach allows for more flexibility, validity, and reliability in the decision-making during critical take-over situations.

References

1. Tanelli M., Toledo-Moreo R., Stanley L. M. (2018) Multifaceted Driver–Vehicle Systems: Toward More Effective Driving Simulations, Reliable Driver Modeling, and Increased Trust and Safety. *IEEE Transactions on Human-Machine Systems.* 48 (1), 1–5. https://doi:0.1109/thms.2017.2784018.
2. *J3016_201401. Taxonomy and Definitions for Terms Related to On-Road Motor Vehicle Automated Driving Systems*. Washington, DC, SAE International.
3. Morales-Alvarez W., Sipele O., Léberon R., Tadjine H. H., Olaverri-Monreal C. (2020) Automated Driving: A Literature Review of the Take Over Request in Conditional Automation. *Electronics*. 9 (12). https://dx.doi.org/10.3390/electronics9122087.
4. Saito T., Wada T., Sonoda K. (2018) Control Authority Transfer Method for Automated-to-Manual Driving via a Shared Authority Mode. *IEEE Transactions on Intelligent Vehicles*. 3 (2), 198–207.
5. Gold C., Körber M., Lechner D., Bengler K. (2016) Taking over Control from Highly Automated Vehicles in Complex Traffic Situations: The Role of Traffic Density. *Human Factors*. 58 (4), 642–652.
6. Framework Document on Automated/Autonomous Vehicles. *World Forum for Harmonization of Vehicle Regulations. 180th Session, Geneva. 2020, 10–12 March*. https://undocs.org/ECE/TRANS/WP.29/2019/34/Rev.2.

7. Proposal for a New UN Regulation on Uniform Provisions Concerning the Approval of Vehicles with Regards to Automated Lane Keeping Systems. *Informal Document GRVA-06-02-Rev.3 6th GRVA, 3–4 March 2020*. Available: https://unece.org/fileadmin/DAM/trans/doc/2020/wp29grva/GRVA-06-02r4e.pdf (Accessed 2 February 2023).
8. Halin A., Verly J. G., Droogenbroeck M. V. (2021) Survey and Synthesis of State of the Art in Driver Monitoring. *Sensors*. 21 (16). https://doi.org/10.3390/s21165558.
9. Eriksson A., Stanton N. A. (2017) Takeover Time in Highly Automated Vehicles: Noncritical Transitions to and from Manual Control. *Human Factors*. 59 (4), 689–705. https://doi:10.1177/0018720816685832.
10. Zhang B., de Winter J., Varotto S., Happee R., Martens M. (2019) Determinants of Take-Over Time from Automated Driving: A Meta-Analysis of 129 Studies. *Transportation Research Part F: Traffic Psychology and Behaviour*. 64, 285–307. https://doi.org/10.1016/j.trf.2019.04.020.
11. Chen C., Lin Z., Zhang S., Chen F., Chen P., Zhang L. (2021) The Compatibility Between the Takeover Process in Conditional Automated Driving and the Current Geometric Design of the Deceleration Lane in Highway. *Sustainability*. 13 (23). https://doi.org/10.3390/su132313403.
12. Zhang S., Pang R., Zhao J. (2019) Reliability of Human-Machine Evaluation Method for Cabs. *International Journal of Performability Engineering*. 15 (5), 1389–1399. https://doi:10.23940/ijpe.19.05.p15.13891399.

Received: 19 February 2026 Accepted: 15 April 2026

Authors' contribution

Dubovsky V. developed algorithms, prepared the manuscript of the article.
Savchenko V. formulated the research task, performed analysis of results.

Information about the authors

Dubovsky V., Cand. Sci. (Tech.), Leading Researcher, The Joint Institute of Mechanical Engineering of the National Academy of Sciences of Belarus

Savchenko V., Cand. Sci. (Tech.), Associate Professor, Head of the Research Center "On-Board Control Systems for Mobile Vehicles", The Joint Institute of Mechanical Engineering of the National Academy of Sciences of Belarus

Address for correspondence

220072, Republic of Belarus,
Minsk, Akademicheskaya St., 12
The Joint Institute of Mechanical Engineering of the National Academy of Sciences of Belarus
Tel.: +375 17 370-07-49
E-mail: vdubovsky.email@gmail.com
Dubovsky Vladimir