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Pavlenko O.V., Yelistratov V.O., Kharkov O.A., Fesenko V.V.
Kremenchuk Mykhailo Ostrohradskyi National University, Kremenchuk, Ukraine

DIAGNOSTIC AND RESTORATION ALGORITHMS FOR MILITARY VEHICLES WITH AUTOMATIC TRANSMISSIONS

The Ukrainian automotive manufacturer KrAZ has supplied the Ukrainian Armed Forces with KrAZ-6510TE tractor units with automatic gearboxes. KrAZ has supplied the Armed Forces of Ukraine (AFU) with KrAZ-6510TE semi-trailer tractors equipped with automatic transmissions. Until now, vehicles fitted with such gearboxes had not been in service with the AFU. In active military units, due to a lack of experience and negligence in maintenance and in timely oil changes in accordance with the operating instructions, nearly all have broken down, rendering the AFU transport units unable to carry out logistics operations due to automatic transmission failures.

The paper examines methods for diagnosing and restoring the operational condition of KrAZ-6510TE semi-trailer tractors, which can be carried out either on-site or at the manufacturing plant through a series of organizational measures. To ensure the rapid resumption of logistics operations for the AFU, algorithms for diagnostic and restoration have been developed for military vehicles equipped with automatic transmissions.

The availability of AutoKrAZ PJSC's technical service can help reduce downtime for KrAZ vehicles during repair and maintenance work performed while the vehicles are in operation.

Key words: semi-trailer tractor, automatic transmission, military service operation, loss of operability, diagnostic and restoration algorithms.

INTRODUCTION

The AutoKrAZ private joint-stock company manufactures the KrAZ-6510TE semi-trailer tractor for the needs of the Ministry of Defence of Ukraine. This vehicle has high off-road capability and is designed for transporting oversized and heavy cargo on all types of roads and off-road. Production of this vehicle is concentrated at the Kremenchuk Automobile Plant, which is the sole national manufacturer with a nearly complete production cycle: from development and manufacturing to warranty and in-service support [1].

The all-wheel-drive KrAZ-6510TE semi-trailer tractor (Fig. 1) has successfully passed departmental trials, during which the military's comments were addressed, and the relevant design documentation was updated. The vehicle has been approved for operation and is supplied by the manufacturer for use by military units of the Armed Forces of Ukraine.

Figure 1 – KrAZ-6510TE Semi-Trailer Tractor

The development of this heavy vehicle model was carried out by the Kremenchuk plant in line with current requirements, with a view to fully meeting the military's logistics vehicle needs. The tractor unit is used as part of a road train to transport heavy military equipment (tanks, armored personnel carriers, artillery or rocket systems) on flatbed trailers or semi-trailers. The vehicle is capable of towing trailers with a gross mass of up to 70 tons.

The all-wheel-drive KrAZ-6510TE semi-trailer tractor with a 6x6 wheel configuration features a cab-over-engine layout [2]. The tractor is equipped with a 9JS150TA-B automatic transmission manufactured by

Shaanxi Fast Auto Drive Group Co., Ltd. (Fast Group). The frame, transmission, and all other vehicle systems are manufactured directly at the KrAZ plant.

The vehicle is equipped with a 460 hp diesel engine, which is most suitable for military use [3], transmitting its torque to the drive wheels through an automatic six-speed hydraulic transmission with a two-speed transfer case. The automatic transmission reduces the driver's workload, making the operation more convenient. Until now, automatic-transmission vehicles had not been used in military units of the Armed Forces of Ukraine. The operation of vehicles with automatic transmissions, particularly in combat conditions, has both advantages and certain disadvantages.

LITERATURE REVIEW AND PROBLEM STATEMENT

The type of transmission fitted to military logistics vehicles affects their operational effectiveness in combat and their ability to meet the army's logistical requirements.

One advantage of using automatic transmissions in wheeled military vehicles is the reduction in driver workload. In combat situations, drivers often work under stressful conditions and with little sleep, which significantly reduces their concentration and alertness. An automatic transmission substantially reduces the physical and mental strain on the driver by simplifying and reducing the number of control operations required. Vehicles with such transmissions are easier to operate in convoys, over rough terrain, and during equipment and casualty evacuations.

Another advantage is improved maneuverability in difficult road conditions [4, 5]. An automatic transmission allows for quick response to changes in terrain and the surrounding situation (mud, inclines, and rubble). Smooth torque delivery reduces the risk of wheel spin or stalling under load.

Military logistics units are often staffed with mobilized personnel, not all of whom have experience with multi-speed manual gearboxes in heavy trucks, or have none at all [6]. The time required for initial training or retraining, conducting exercises, and driver instruction for vehicles equipped with automatic transmissions is shorter than for vehicles equipped with manual transmissions. In such situations, soldiers who have driven civilian vehicles find it easier and quicker to adapt to driving heavy-duty military vehicles.

Modern automatic transmissions (especially hydromechanical ones with electronic control, or robotic ones) optimize engine speed and sometimes provide fuel savings compared to their manual counterparts.

The use of automatic transmissions reduces clutch and drivetrain wear [7]. Such a transmission protects the driver from making mistakes (for example, abrupt gear engagement, improper clutch use, etc.). Power flow transmission is significantly smoother, which extends the service life of the transmission under intensive operation.

Heavily loaded vehicles and road trains with automatic transmissions have greater off-road capability. In military tractors (e.g., Oshkosh HEMTT, MAN HX, Tatra Force), an automatic transmission provides better torque utilization when pulling away from a standstill with a heavy load [8]. The resumption of vehicle movement after stops is also faster.

When driving in a convoy or escort, it is important to minimize any speed drops. An automatic transmission ensures more uniform movement without loss of convoy pace.

However, operating vehicles with automatic transmissions in the armed forces poses several problems. The universally recognized ones include: the complexity of repair under field conditions; sensitivity to lubricant properties and quality of maintenance; higher cost and greater curb weight of the vehicle.

The higher unit cost and greater weight are inherent characteristics of such a solution. For example, a manual gearbox (ZF 16S 1820, 16-speed) weighs 270-320 kg; an automated manual transmission (ZF TraXon 12 TX) weighs 340-380 kg; a fully automatic transmission (Allison 4500 SP / 4800 SP, 6-speed) weighs 420-480 kg. Thus, the maximum weight difference between units reaches 100 kg.

The properties of lubricants and the quality and timeliness of maintenance are of decisive importance for the long-term operation of vehicles. Thus, before the war began, several dozen KrAZ-6510TE semi-trailer tractors were commissioned into the AFU. By 2024, almost all of them had broken down.

PURPOSE AND OBJECTIVE OF THE STUDY

A number of KrAZ-6510TE vehicles that had broken down were returned to the manufacturer. Upon inspection, it was found that most automatic transmissions had failed due to negligence in maintenance and in timely oil and filter element replacement. Consequently, maintenance personnel had either not been trained or had negligently performed their professional duties; the supply and timely replacement of the necessary filters and corresponding lubricants had not been ensured.

Thus, the AFU logistics units face the challenge of rapidly and reliably ensuring the technical readiness of vehicles equipped with automatic transmissions. To address this, it is proposed to develop effective diagnostic and restoration algorithms for military tractor vehicles with automatic transmissions.

RESEARCH RESULTS

Technical readiness algorithms are models and methodologies for maintaining equipment (especially in security forces) in operational condition. They may include calculating readiness indicators, reliability management, maintenance planning, equipment replacement prioritization, and applying process and systems approaches for continuous monitoring and improvement of reliability. In other words, they represent a set of actions to ensure that equipment is ready to perform tasks at any given moment. In general, there are two approaches to ensuring the technical readiness of vehicles: maintaining operability and restoring it.

However, failures of automatic transmissions or the entire powertrain in vehicles in service with AFU military units are events that have already occurred. And this is by no means an isolated incident – there have been more than ten cases of transmission failure out of the thirty military vehicles manufactured and put into service. If the automatic gearbox fails, the tractor becomes completely inoperable – it is, in effect, unable to move.

Therefore, the following diagnostic and restoration algorithms for military tractor vehicles with automatic transmissions are proposed for analysis, illustrated in the fig. 2 as a flowchart.

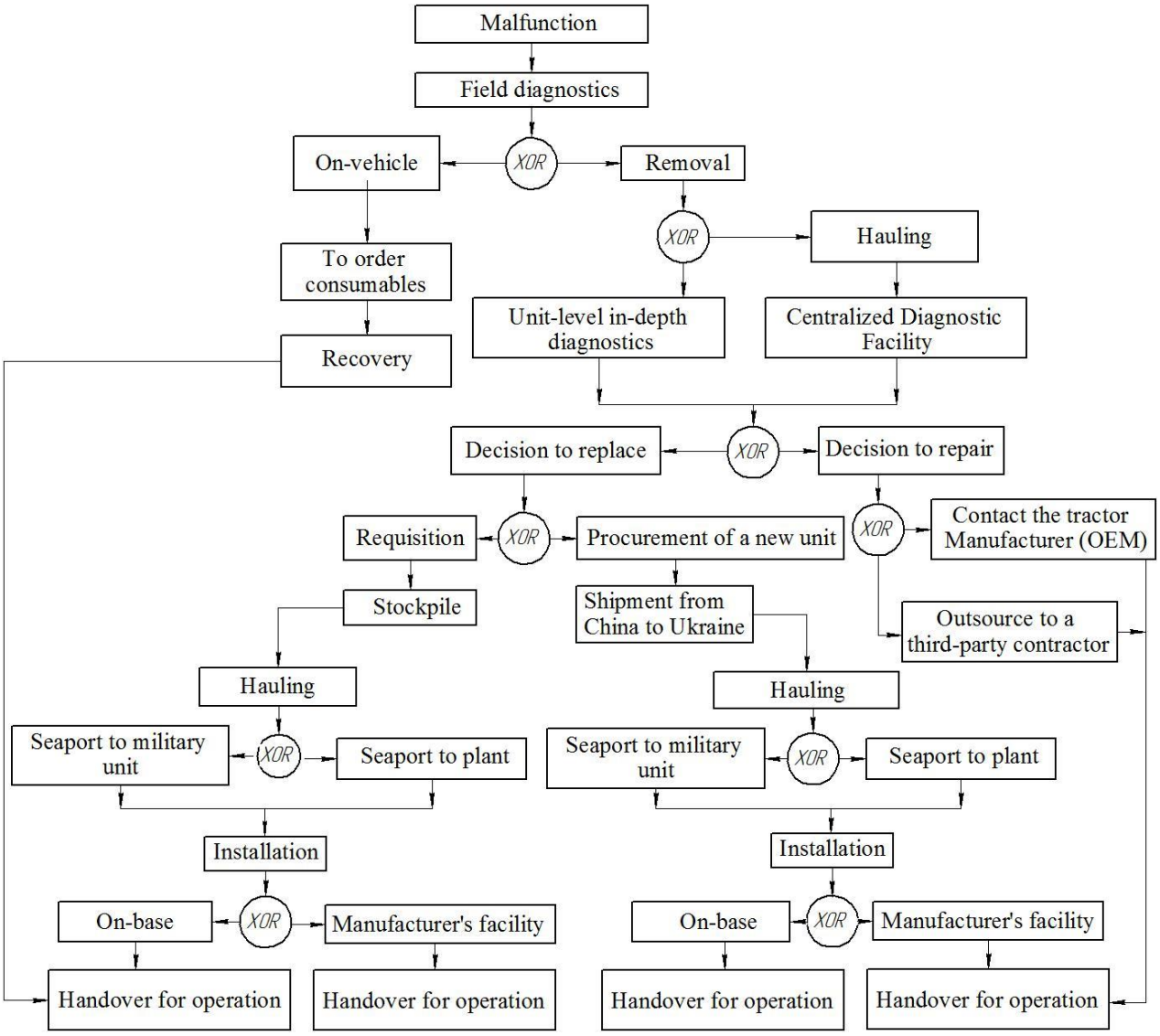

Figure 2 – Flowchart for diagnosing and restoring the operability of military tractor vehicles with automatic transmissions

The operational condition of an automatic transmission (and consequently the entire vehicle) cannot be restored without removing it from the vehicle. Removal of the transmission is carried out after testing with mobile diagnostic tools in accordance with the operating instructions for the relevant automatic transmission. In effect, this is done to confirm that the equipment cannot be used and to serve as the basis for

a more thorough diagnostic assessment and subsequent repairs. Such diagnostics and subsequent repairs require specialized diagnostic and repair equipment.

In-depth diagnostics and the subsequent repair of an automatic transmission using specialized equipment and tools require:

1. The availability of specialized means for performing technical interventions.
2. Training of personnel on how to use this equipment.
3. The availability of a dedicated facility to house such equipment.

Under current conditions, the following options for organizing in-depth diagnostics and repair of military vehicles with automatic transmissions can be considered.

1. Each military unit operating such vehicles establishes its own in-depth diagnostic and repair section for automatic transmissions.

Advantages: speed and convenience for the military unit in carrying out diagnostic and repair work on automatic transmissions.

Disadvantages of this option include: the need to set up a dedicated sub-unit to deal with this specific type of vehicle technical readiness support; the need to staff this sub-unit with highly qualified specialists and fit it with specialized tools, equipment, and reference literature; organizing an extensive supply chain for the necessary spare parts (assemblies); increased costs of funding the transport sub-units of all military units.

2. An in-depth diagnostic and repair section for automatic transmissions is organized at a rear military unit. Given Ukraine's well-developed road network and relatively small size, it is reasonable to assume that a single such section will suffice overall.

Advantages: given the number of semi-trailer tractors intended for the transportation of heavy equipment and the concentration of the greater part of them in individual military units, lower costs of organizing such a section would be achieved; the number of personnel requiring training would be minimal, and it would be easier to ensure the supply of the necessary spare parts.

Disadvantages: increased expenditure of material and human resources, as well as time for transporting failed automatic transmissions (vehicles) to the diagnostic and repair location and then back to the respective military units; and, as in the previous option, the need to staff the sub-unit with highly qualified specialists, fit it with specialized tools, equipment and reference literature, and the need to establish logistics supply chains for spare parts (assemblies), mainly from abroad.

3. The Ministry of Defense organizes full technical service for the automatic transmissions or vehicles equipped with them that have been commissioned into the AFU, at the manufacturer's territory, i.e., at KrAZ.

Advantages: minimal costs of organizing a diagnostic and repair section for automatic transmissions (vehicles); the availability of highly qualified personnel with experience working on automatic transmission assemblies who require virtually no additional training; established logistics supply chains for spare parts (assemblies) from domestic enterprises and from abroad; the possibility of carrying out diagnostics, maintenance and repair of other vehicle assemblies directly at the plant; reduction of the time required to perform the necessary technical interventions while simultaneously improving their quality.

Disadvantages: as in the previous option, greater expenditure of material and human resources, as well as time for transporting failed automatic transmissions (vehicles) to the diagnostic and repair location and then back to the respective military units.

To obtain information on the condition of the components of a failed automatic transmission, its partial disassembly may be permitted. Disassembly of automatic transmissions will require specialized equipment, which is more easily and conveniently located at a specialized automotive manufacturing plant.

Following in-depth diagnostics of the automatic transmission, a decision is made on whether to repair it or replace it. Once a decision is made to carry out repairs in Ukraine, the urgent question arises of where they are to be performed. If a decision is made to replace the unit, the question of the method and timeframe for obtaining a new automatic transmission arises. The installation of a new or repaired automatic transmission onto the vehicle from which it was removed also presents a considerable challenge for active military units. Again, these tasks are easier and quicker to carry out at the vehicle manufacturer's facility, which has its own experience with such operations.

From an organizational perspective, the decision to replace a failed automatic transmission is straightforward and very fast. To this end, one of the following courses of action must be implemented:

1. Order the assembly from a domestic warehouse (if available), transport the assembly to the location of the tractor vehicle, and install the transmission on the tractor.

2. Purchase a new automatic transmission from a foreign manufacturer (China), wait for it to arrive in Ukraine (3-4 months), transport it from the port to the location of the tractor vehicle, and install the transmission on the tractor.

Implementing the first course of action entails additional financial costs for purchasing the required number of automatic transmissions and for their preservation. The question of how many automatic transmissions need to be held in storage will remain open. It is obvious that this number will differ substantially between peacetime and wartime. It is likely that such an approach would also be advisable for the engines of military vehicles. The engine is also supplied from China (manufactured by Weichai Power Co., Ltd.). Having a stock of assemblies at a central warehouse enables the full benefits of the assembly-replacement method of organizing vehicle repair.

For the organization of the first course of action, a single, central storage warehouse for automatic transmissions and vehicle engines would suffice. This warehouse does not necessarily have to be located at an AFU repair unit. Nor is there a need to construct a new specialized facility, create warehouse infrastructure, or establish logistics. The existing warehouse infrastructure and logistics routes of the KrAZ enterprise, which already purchases and stores the said assemblies as part of its own production schedule, can be utilized. It is sufficient to purchase a somewhat larger number of engines and automatic transmissions, which would be stored at the plant's existing warehouse.

Furthermore, if spare assemblies are stored at the vehicle manufacturer's facility, it would be advisable to arrange replacement of failed transmissions and engines there rather than at a military unit. The existing KrAZ production base and the plant's workers' qualifications enable these operations to be performed quickly and to a high standard. However, this would require transporting the entire vehicle to the plant. However, given all of the above, this may not be a significant disadvantage.

Implementation of the second course of action requires an agreement with the foreign manufacturer of transmissions and engines to supply individual units as needed. It is understood that such an agreement can be formalized upon the conclusion of the main contract for a large batch of assemblies. The purchase of automatic transmissions and vehicle engines will take place in batches over a specified period, taking into account the vehicle production schedule, contract availability, and other factors. The transportation time for assemblies from China is at least two months. This means that vehicles will be out of service for at least 2-3 months due to logistical constraints alone. In comparison, the time required to transport the same assemblies within Ukraine is negligible. Once they arrive on Ukrainian territory, they are transported either to the military unit or to the automobile plant. This stage is not significant in terms of timelines or financial costs. Similar to the first course of action, the installation of the delivered assemblies can be carried out either at the military unit's location or at the automobile plant. A significant drawback of this course of action is that, throughout the period when spare assemblies are being delivered to the end consumer, the failed vehicles will be idle for an excessively long time, awaiting repair.

The repair of failed assemblies from military vehicles can also be carried out in two ways: by contacting the vehicle manufacturer or by finding a third-party contractor capable of repairing automatic transmissions and engines of foreign manufacture on the territory of Ukraine in the civilian sector.

Both approaches require equipping the repair organization with specialized equipment and tools, and training workers to perform repair interventions on assemblies from the Chinese manufacturer Weichai Power Co. As an alternative, it is possible to re-equip the trucks with powertrains featuring automatic transmissions from a different manufacturer. However, given that automatic transmissions for heavy trucks are not produced in Ukraine, this potential manufacturer would again be of foreign origin, which entails the same set of problems. There would also be a prolonged delay in obtaining the Ministry of Defense of Ukraine approval for the technical documentation. Such a delay could last several months.

CONCLUSION

The properties of lubricants and the quality and timeliness of maintenance are of decisive importance for the long-term operation of vehicles equipped with automatic transmissions. Failure to comply with these requirements prevents AFU transport units from conducting logistics operations due to automatic transmission failures in military vehicles.

To ensure the rapid resumption of logistics operations for the AFU, diagnostic and restoration algorithms have been developed for military vehicles equipped with automatic transmissions.

To mitigate the negative consequences of failures in vehicles with automatic transmissions, it is necessary to organize training for military vehicle drivers and maintenance personnel for the timely and quality execution (to the extent possible in an active army) of instructions on the organization of

maintenance and repair of motor vehicles in military units, and to ensure the availability, complete and timely supply of the necessary range of consumables and components for the vehicles in service.

The removal, disassembly, repair, and reassembly of an automatic transmission, which is a highly complex assembly, requires specially trained repair personnel, specialized tools, fixtures, and equipment, as well as a set of spare parts and materials. Therefore, the quality execution of the said work within military units appears highly doubtful.

In view of this, a realistic and effective solution in the event of the need to rectify a failure of a military vehicle's automatic transmission is the replacement of the entire assembly without disassembly, which is most appropriately carried out at the vehicle manufacturer's plant.

It is also more efficient to use the enterprise's available, accessible warehouses to store the necessary quantity and range of spare parts for the vehicles.

The availability of AutoKrAZ PJSC's technical service can help reduce downtime for KrAZ vehicles during repair and maintenance operations throughout their use.

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Павленко О.В., Єлістратов В.О, Харьков О.А., Фесенко В.В. **Алгоритми діагностування та відновлення працездатності військових автомобілів з автоматичними коробками передач.**

Вітчизняний виробник автомобільної техніки КрАЗ поставив на озброєння ЗСУ сідельні тягачі КрАЗ-6510ТЕ з автоматичними коробками передач. До цього часу автомобілі з такими коробками передач в ЗСУ не експлуатувалися. В діючих військових підрозділах через недбальство щодо технічного обслуговування та вчасної заміни мастила відповідно до інструкцій з експлуатації майже всі вони вийшли з ладу, що призвело до неможливості виконання логістичних операцій транспортними підрозділами ЗСУ через відмови автоматичних коробок передач автомобілів.

У роботі розглянуто способи діагностування та відновлення працездатного стану сідельних тягачів КрАЗ-6510ТЕ, які можна організувати безпосередньо на місцях або на підприємстві-виробнику за рахунок низки організаційних заходів. Для забезпечення швидкого поновлення операцій логістичного направлення для потреб ЗСУ створені алгоритми діагностування та відновлення працездатності військових автомобілів з автоматичними коробками передач.

Наявність технічного сервісу ПАТ «АвтоКрАЗ» може забезпечити зменшення простою техніки КрАЗ під час проведення ремонтних робіт і робіт з технічного обслуговування машин в ході їх

експлуатації.

Ключові слова: сідельний тягач, автоматична коробка передач, експлуатація в збройних силах, втрата працездатності, алгоритми діагностування та відновлення працездатності.

ПАВЛЕНКО Олександр Володимирович, кандидат технічних наук, доцент кафедри автомобілів і тракторів, Кременчуцький національний університет імені Михайла Остроградського, e-mail: alexander6170101@gmail.com, ORCID: 0000-0001-8277-340x.

ЄЛІСТРАТОВ Вячеслав Олександрович, кандидат технічних наук, доцент кафедри автомобілів і тракторів, Кременчуцький національний університет імені Михайла Остроградського, e-mail: yelisslava@gmail.com, ORCID: 0000-0001-7931-7761.

ХАРЬКОВ Олександр Андрійович, старший викладач кафедри автомобілів і тракторів, Кременчуцький національний університет імені Михайла Остроградського, e-mail: alexkharkov37@gmail.com, ORCID: 0000-0003-2561-4837.

ФЕСЕНКО Володимир Володимирович, студент кафедри автомобілів і тракторів, Кременчуцький національний університет імені Михайла Остроградського, e-mail: ghost24vov65@gmai.com, ORCID: 0000-0000-0000-0000.

Olexandr PAVLENKO, PhD, Associate Professor of the Department of automobiles and tractors Kremenchuk Mykhailo Ostrohradskyi National University, e-mail: alexander6170101@gmail.com, ORCID: 0000-0001-8277-340x.

Viacheslav YELISTRATOV, PhD, Associate Professor of the Department of automobiles and tractors Kremenchuk Mykhailo Ostrohradskyi National University, e-mail: yelisslava@gmail.com, ORCID: 0000-0001-7931-7761.

Olexandr KHARKOV, Senior Lecturer of the Department of automobiles and tractors Kremenchuk Mykhailo Ostrohradskyi National University, e-mail: alexkharkov37@gmail.com, ORCID: 0000-0003-2561-4837.

Volodymyr FESENKO, student of the Department of automobiles and tractors Kremenchuk Mykhailo Ostrohradskyi National University, e-mail: ghost24vov65@gmai.com, ORCID: 0000-0000-0000-0000.

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