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3D-printing in the automotive industry

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Abstract. Additive manufacturing is of great importance in the design and manufacture of automobiles. The number of applications for 3D printing in manufacturing continues to expand on an annual basis. In the recent past, 3D printing was primarily utilized for the fabrication of prototypes. However, there has been a notable shift in the automotive manufacturing sector, with an increasing number of manufacturers adopting the technology for the production of significant automotive components. Additive manufacturing is employed to create design iterations, improve quality through cost-effective prototyping, and produce custom tooling parts. However, there are other areas of 3D-printing in the automotive industry that are more radically transforming products and supply chains. Additive technologies and the new materials used enable the creation of various combinations, both for producing parts with increased strength characteristics and for using soft materials in the interior of the cabin. Additive manufacturing aims to improve manufacturing processes and produce high-quality products in a short time. This article describes the main trends in the integration of 3D-printing technologies into the design and manufacturing processes of cars across various classes and companies. The main purpose of this article is to highlight the key aspects of additive manufacturing in the automotive industry. The use of these trends opens up new opportunities in the automotive industry of Kazakhstan.

Keywords: Additive manufacturing, 3D-printing, manufacturing, automotive, mechanical engineering, metal printing.

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Introduction

Speeding up the product design phase during new product development is key in any industry. Fortunately, at this stage, 3D-printing can replace expensive and time-consuming CNC (Computer numerical control) manufacturing. More precisely, it allows designers to go through several iterations at minimal cost before deciding on the final product. The process is as follows: once designers have identified a user's need and generated ideas to meet that need, they develop a prototype. The next step is to test this prototype in order to improve its design. We also call this iterative process rapid prototyping [1].

Rapid prototyping begins with the creation of a computer-aided design (CAD) file for the first iteration of the part. The user can then import the part design file into the 3D-printer software and print it. The prototype will be ready to be tested, evaluated, and modified for the next iteration within a few hours to 1-2 days.

However, many 3D-printers are limited to prototype-quality parts only. When using these printers, the design may need to be modified to meet traditional manufacturing constraints. This was the case a few years ago [2]. At the moment, there are companies in the field of mechanical engineering that integrate additive technologies for mass production. Someone makes complex parts, someone combines several units into one, someone is looking for ways to lighten the part without loss and strength [3].

The methodology

The Volkswagen Group is actively exploring HP's (Hewlett Packard) high-performance binder blasting technology for production vehicles. Most of Volkswagen's additive manufacturing (AM) activities are carried out in a state-of-the-art 3D-printing center located on the premises of the plant in Autostadt, Wolfsburg. The facility serves as a center for testing and learning about AM technology, as well as tooling and finished parts manufacturing. Figure 1 shows examples of the company's work on mass printing of metal parts. High-volume manufacturing is usually done in additive manufacturing in partnership with AM's external additive manufacturing services. Printed Volkswagen metal parts shown in figure1.

Figure 1. Bulk printing of metal parts [3]

At the end of 2018, Volkswagen expanded its AM capabilities at the Wolfsburg plant by implementing the Additive Industries MetalFab 1 system for 3D-printing state-of-the-art tools and spare parts. An important achievement resulting from a recent partnership with HP and GKN (Guest, Keen and Nettlefolds Limited) is the introduction of HP's new metal binder blasting technology. This cooperation enables Volkswagen's tooling division at the Wolfsburg plant to engage in the actual 3D series production of numerous parts. Although specific parts have not yet been definitively identified (although a sample of 10,000 miniature models has been made for sale), initial expectations suggest that they will be between 2 and 5 cm long and are mostly made of steel alloys.

In addition, the development of electric vehicles (EVs) serves as a driving force for the integration of new production technologies into Volkswagen. During the development of the R Pikes Peak electric racing car, Volkswagen engineers made extensive use of 3D-printing to produce many individual parts. These parts, including cable mounts and switches, are effectively used in test drives and finished race cars, highlighting the practical application of additive manufacturing in the context of electric vehicles [4].

Indeed, the advantage of using AM is the potential to produce components with less weight to create vehicles that consume less fuel. Thus, industrial design software plays a central role. Over the years, CAD and CAM (Computer-aided manufacturing) solutions have improved significantly, especially for additive manufacturing. These often include generative design, topology optimization, and lattice creation tools that reduce the overall weight of parts while maintaining or improving their functionality. Lighter parts often turn out to be more complex. But because AM is not limited in terms of design freedom, unlike traditional methods, complexity is not an issue. It should be noted that simplifying parts is also possible thanks to 3D-printing, by combining multiple parts into a single design. Thus, the complexity of assembly could be reduced in the long run if a large number of these parts were to be produced.

Additive manufacturing also means more personalization options. In fact, some luxury car manufacturers are already using 3D-printing to create designs tailored to customer requirements. Traditional manufacturing methods such as CNC or injection molding would not be able to deliver unique parts in a competitive timeframe. The cost of manufacturing such parts would also be significantly different. In addition, personalization can also be used to deliver spare parts, such as repairing an old model car [5].

Ford's aluminum intake manifold, made using GE (General Electric) Additive's Concept Laser X LINE 2000R 3D-printing technology, was installed in a 1977 Hoonitruck. This part, shown in Figure 2, designed to supply a fuel-air mixture to the engine cylinders, is the largest automotive part ever produced by 3D-printing. The printing process took five days.

Figure 2. 3D-printed Ford aluminum intake manifold [6]

Ford is a leading research center in the field of industrial implementation of additive manufacturing. As early as 1986, the company invested in SLA 3 (Stereolithography), the first-ever 3D-printer. Ford claimed the superiority of this technology in creating new prototype parts with greater speed and efficiency. To date, the company has produced more than 500,000 parts and has achieved significant savings in cost and operating time. At its advanced manufacturing center in Detroit, Ford has invested in a variety of 3D-printing technologies such as FDM (Fused deposition modeling), SLS (selective laser sintering), and powder 3D-printers [6].

In 2020, the BMW Group opened an additive manufacturing campus in the immediate vicinity of Munich. The campus cost around €15 million to build and currently has around 50 industrial plants for metal and plastics processing. The production of prototypes, serial parts, research and development and training of employees without tooling production is carried out here.

This significant financial contribution is a testament to the BMW Group's trust in 3D-printing technology. Like other automakers, the company began investing in additive manufacturing as early as 1991 to create prototype concept cars. In the following years, small series of parts for various cars were launched, including DTM, Rolls-Royce Phantom, BMW i8 Roadster and MINI racing cars. In total, 300,000 3D parts were printed in a year [7].

A study by Deloitte found that the changes described above will have an impact on supply chains. Today's equipment manufacturers are increasingly outsourcing their components. The report notes: "With the development of equipment manufacturers' products, there is a double change: a decrease in the length of supply chains and an increase in the contribution of manufacturers themselves to value creation" [8].

An important aspect of additive manufacturing can be the simplification and reduction of the complex supply chains that characterize the modern automotive industry. Manufacturers work with a variety of suppliers to source a variety of automotive components and are constantly striving to shorten the length of their supply chains.

In this way, companies can take advantage of additive manufacturing to transform supply chains by producing on-site and reducing spare parts inventory [8].

Generative design is a process of design research. Designers or engineers enter design goals into generative design software, as well as parameters such as performance or spatial requirements, materials, manufacturing methods, and cost constraints. The software explores all possible solutions, quickly generating alternative designs. It tests and learns from each iteration, determining what works and what doesn't [9].

Using generative design and additive manufacturing, General Motors was able to combine eight different seat bracket components into a single 3D-printed part, Figure 3.

Figure 3. Generative design for General Motors [10]

The combination of generative design and additive manufacturing has the potential to radically transform the automotive industry, overcoming the historical limitations of traditional manufacturing tools. These innovations enable the creation of complex geometries and organic structures with minimal capital investment, opening up new horizons for vehicle design and manufacturing [10].

Findings/Discussion

Over the years, improvements in material manufacturing technology have made it possible to use more materials for the AM process. Automotive parts are typically made of high-performance polymers, carbon fiber-reinforced thermoplastics, and metals. Equipment manufacturers actively sought to use lighter materials such as carbon fiber and aluminum in the car body. Thus, materials adapted for additive manufacturing can allow more properties to be incorporated into the final products, but are also crucial in the development of functional prototypes.

BASF Forward AM is working together with its customers and OEMs to develop innovative products based on the implementation of additive manufacturing. Forward AM has worked with Daimler to develop a new engine mount that reduces vibration transmission and provides maximum passenger comfort. In the last decade, engine mounts have mainly been made of fiber-reinforced polymers molded under pressure. However, the need for shorter development cycles and lower costs has put this traditional design process and materials at risk. BASF Forward AM has eliminated the very costly need for new molds with each design modification by using AM technologies in the process. The challenge was to meet the stringent thermal and mechanical performance requirements under the test conditions. They needed a very rigid and heat-resistant material. The ideal solution was Ultrasint PA6 MF (mineral-filled polyamide 6 superior to PA11 and PA12), which produced test-ready prototypes in less than 48 hours (instead of several weeks with injection molding). Although the design of the 3D-printed part looked different, it could be used like the original as a fully functional prototype during the development phase when there was no injection molding part available. Thus, the key point was to find a suitable substitute material to replicate the characteristics of the injection molded part [11].

In the electric vehicle sector, Olli is present and has developed an autonomous electric minibus using 3D-printing technology. This minibus was created in 2016 by Local Motors. The manufacturer claims that approximately 80% of the components of this vehicle were made with a 3D-printer, resulting in a 90% reduction in overall production time. The maximum speed of the minibus is limited to 40 km/h, making the Olli an ideal vehicle for use in urban centers, university campuses and hospitals. Olli bus shown at figure 4. Olli's predecessor was the Strati roadster, a two-seater electric car in which 75% of the parts were also produced using 3D-printing [12].

Figure 4. 3D printed Olli minibus [12]

In addition, as the demand for connected vehicles grows, so does the need for electronic devices such as sensors and antennas inside the vehicle. With this increase comes the need to design and manufacture more compact and complex electronics. Based on micro and nanoscale 3D-printing technologies, it is possible to independently develop more complex electronic

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components that can be directly embedded in the car. Additive 3D-printing can reduce the cost and development time to create these devices.

As already noted, customization provides a wide range of possibilities. For example, MINI customers can now personalize their vehicles by creating a unique design for the side strip and side inserts in the cabin. More than 140,000 components have been 3D-printed in various BMW Group projects [13]. The table 1 shows the range of materials that are used in the automotive industry, as well as the respective applications.

Table 1. AM materials suitable for automotive applications [12]

Application	Process	Material	Functions	Example Part
Under the hood	SLS	Nylon	Heat-resistant functional parts	Battery Cover
Interior accessories	Service Level Agreement (SLA)	Resin	Customized cosmetic components	Prototype console
Duct	SLS	Nylon	Flexible air ducts and bellows	Air conditioning ducts
Full-scale panels	Industrial Service Level Agreement	Resin	Oversized parts with a surface finish comparable to injection molding, allowing grinding and painting	Front bumper
Molded metal brackets and handles	SLA & Cast	Wax	Metal parts made from 3D-printed templates	Generator Mounting Bracket
Complex metal components	DMLS	Metal	Durable, lightweight, functional metal parts	Wishbones
Framing	Material blasting	Photopolymer	Custom End-Use Screen Frames	Dashboard interface
Traffic light	Service Level Agreement (SLA)	Resin	Fully transparent models with high detail	Prototype headlights

Designed and assembled in Los Angeles, the concept and process behind the Czinger 21C hypercar is an innovative approach to car manufacturing. The company's pioneering Divergent Adaptive Production System (DAPS) dramatically automates the process of designing and creating most parts for the 21C. It uses artificial intelligence to optimize the shape and design of parts, simulating natural samples to improve strength and efficiency. This process takes minimal time, reducing the manual labor of engineers and ensuring the creation of parts with unique shapes using additive technologies. The assembled chassis of the Czinger C21 model is shown in Figure 5.

Figure 5. Printed Czinger C21 chassis [14]

DAPS allows you to create parts using one of the largest 3D-printers in the world, powered by 12 lasers, which significantly increases the speed of printing. This method also minimizes material waste through an optimized production process. Most of the parts, with the exception of some elements such as carbon fiber panels, wheels and interior elements, are produced using 3D-printing technology.

Manufacturing involves combining the created parts to form finished components. The latest adhesives developed by the company are used to connect the elements, which provide a strong bond, bypassing traditional fastening mechanisms. Assembly is carried out by a robot with an integrated 3D-printer, which, thanks to the optimization of the process by artificial intelligence, can quickly switch between different additive manufacturing tasks with minimal delays. This unique approach to production ensures high efficiency and quality of the final product. Figure 6 shows a complex shape of motor mounts printed from metal using the topological optimization of the model [14].

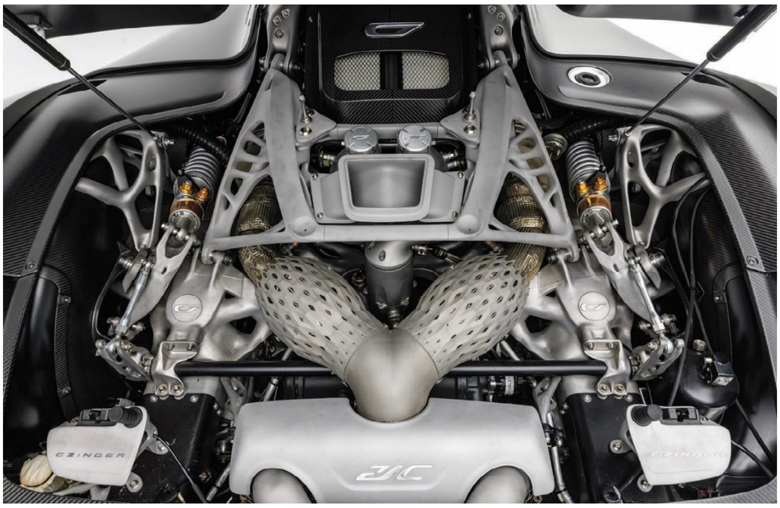

Figure 6. Printed part of the Czinger C21 motor [14]

In recent years, automakers have had to master new business models to achieve growth. In Jabil's report on trends in the automotive industry, you can read that 71% of automotive companies have a timeline to market of less than 2 years. Many are turning to new technologies, including additive manufacturing, to maintain short development cycles and reduce costs. Vehicle electrification is also of interest, with about 50% of automakers aiming to become leaders in all-electric vehicles (EVs) in the near future [15]. As the industry moves away from internal combustion engines, 3D-printing is becoming an increasingly popular solution capable of accelerating the development of lighter parts for electric vehicles. Indeed, low weight is crucial for electric vehicles, as it directly affects battery life.

The dawn of mainstream electric vehicles has arrived, and almost all major automakers are now offering all-electric alternatives to traditional internal combustion vehicles. This is in line with the major sustainability trends in today's world, where the use of fossil fuels and other fossil fuel-dependent technologies is being reduced. Additive manufacturing technologies, which were used in the past by the automotive industry, now open up opportunities for the automotive sector, where great innovations can be achieved through its implementation. Parts manufactured with additives provide a comprehensive, optimized design as well as improve material efficiency. Moreover, system-wide benefits are also possible and promised in terms of optimizing supply chains and logistics operations. This article presents these advantages, the reason for the growing interest and future prospects for integrated additive manufacturing based on metals and polymers in additive manufacturing in traditional automotive production chains. The trend shows a high degree of integration of additive technologies with modern production facilities at automotive plants. There is a lot of progress in the use of 3D-printing technologies in the creation of prototypes and experimental samples to full-fledged industrial and mass parts.

Conclusion

In conclusion, the forecast for the development of additive technologies in the automotive industry promises profound changes. These technologies represent a promising area that has the potential to revolutionize the way vehicles are designed, manufactured and operated. They provide the ability to create individually customizable parts and components, which improves the adaptability of vehicles to different needs and operating conditions. Additive manufacturing can also significantly reduce weight and increase the strength of parts, resulting in more efficient and environmentally friendly vehicles.

In addition, these innovations reduce the time and cost of producing new models, allowing for a more flexible and faster response to market requirements and design changes. Overall, automotive additive manufacturing represents a key enabler for achieving new levels of innovation, quality, and competitiveness in the industry. By optimizing the topology, it is possible to reduce the weight of parts without losing their strength, which is now actively used in motorsport. The use of high-end materials such as titanium allows for the printing of ultra-strong and lightweight parts by combining multiple complex components into a single unit.

In the coming years, additive manufacturing can be expected to become an integral part of the automotive manufacturing process. The automotive industry in Kazakhstan is developing rapidly; recently, new plants and factories have been opening more and more often. And it means that additive manufacturing can be used to optimize manufacturing processes. Advances in this area will contribute to the development of new models and solutions that can meet the growing needs of both consumers and manufacturers. In this way, additive manufacturing can become a driving force for progress in the automotive industry, opening up new horizons for engineering innovation and sustainability. Generative design become more popular and more manufacturer around the world will use it in their vehicles.

The contribution of the authors.

Ibraim Alibek Samatuly – text writing, data collection, data sorting, trend analysis and technology application of additive technologies in the automotive industry

Absadykov Bakhyt Narekbayevich – scientific supervisor of the doctoral student – checking the analysis and data, summarizing, concluding, checking the integrity of the article.

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Автомобиль өнеркәсібіндегі 3D баспа

Аңдатпа. Аддитивті өндіріс автомобильдерді жобалау мен өндіруде үлкен маңызға ие. Жылдан жылға өндірісте 3D басып шығару үшін пайдалану жағдайларының саны өсуде. Бірнеше жыл бұрын 3d басып шығару негізінен прототиптер мен макеттерді жасау үшін қолданылған, бірақ қазір көбірек өндірушілер автомобильдің негізгі компоненттерін басып шығара бастады. Аддитивті өндіріс дизайн итерацияларын жасау, үнемді прототиптеу арқылы сапаны жақсарту және тапсырыс бойынша құрал-саймандар бөлшектерін жасау үшін қолданылады. Дегенмен, автомобиль өнеркәсібінде өнімдер мен жеткізу тізбегін түбегейлі өзгертетін 3D басып шығарудың басқа да салалары бар. Аддитивті технологиялар мен қолданылатын жаңа материалдар беріктік сипаттамалары жоғарылаған бөлшектерді шығару үшін де, кабинаның ішкі бөлігінде жұмсақ материалдарды пайдалану үшін де әртүрлі комбинацияларды жасауға мүмкіндік береді. Аддитивті өндіріс өндірістік процестерді жақсартуға және қысқа мерзімде жоғары сапалы өнім шығаруға бағытталған. Бұл мақалада әртүрлі класстар мен компаниялардағы автомобильдерді жобалау және өндіру процестеріне 3D басып шығару технологияларын біріктірудің негізгі тенденциялары сипатталған. Бұл мақаланың негізгі мақсаты-автомобиль өнеркәсібіндегі қоспалар өндірісінің негізгі аспектілерін бөліп көрсету. Осы үрдістерді пайдалану Қазақстанның автомобиль өнеркәсібінде жаңа мүмкіндіктер ашады.

Түйін сөздер: Аддитивті өндіріс, 3d басып шығару, өндіріс, автомобиль, машина жасау.

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3D-печать в автомобильной промышленности

Аннотация. Аддитивное производство имеет огромное значение при проектировании и производстве автомобилей. С каждым годом количество вариантов использования 3D-печати в производстве продолжает расти. Несколько лет назад 3D-печать в основном использовалась для создания прототипов, но сейчас все больше и больше производителей начинают печатать основные компоненты автомобилей. Аддитивное производство используется для создания различных вариантов дизайна, повышения качества за счет экономичного прототипирования и изготовления деталей на заказ. Однако в автомобильной промышленности существуют и другие области 3D-печати, которые более радикально трансформируют продукцию и цепочки поставок. Аддитивные технологии и используемые новые материалы позволяют создавать различные комбинации как для изготовления деталей с повышенными прочностными характеристиками, так и для использования мягких материалов в интерьере салона. Аддитивное производство направлено на совершенствование производственных процессов и производство высококачественной продукции в короткие сроки. В этой статье описаны основные тенденции в области интеграции технологий 3D-печати в процессы проектирования и производства автомобилей различных классов и компаний. Основная цель этой статьи - осветить ключевые аспекты аддитивного производства в автомобильной промышленности. Использование этих тенденций открывает новые возможности в автомобильной промышленности Казахстана.

Ключевые слова: Аддитивное производство, 3D-печать, обрабатывающая промышленность, автомобилестроение, машиностроение, печать по металлу.

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