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Design and production of an environmentally friendly cabin type full automation paint removal machine

Çevre dostu kabin tipi tam otomasyon boya temizleme makinesi tasarımı ve üretimi

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Highlights

- *The study extensively examines a machine specifically designed for removing layers on wooden surfaces.*
- *The design enables operators to adjust air pressure, nozzle settings, and feed speed.*
- *Lower blast angles are found to be more effective in paint removal, particularly on hard surfaces.*
- *Optimal process involves adjusting air pressure based on surface hardness and nozzle diameter.*
- *The machine offers versatile combinations for paint removal without surface damage.*

Graphical Abstract

This study introduces a machine allowing operators to customize air pressure, nozzle settings, and blast parameters for efficient paint removal on wood. Findings emphasize the impact of blasting angles and nozzle diameter on surface wear, crucial considerations for optimal performance and process efficiency.

Figure. Representation of the device designed for removing aged layers on wooden surfaces.

Aim

This study details the design of a machine for removing aged layers on wood surfaces, allowing operators to adjust to parameters.

Design & Methodology

The design and methodology of the study encompass the detailed design of a machine specifically developed for the removal of aged layers on wood and wooden surfaces.

Originality

The paint removal machine described in the article is unique and innovative for the field, as it was developed exclusively for wooden surfaces.

Findings

In the paint removal industry, devices manufactured for use on hard surfaces such as metal are attempted to be made suitable for wooden surfaces through various upgrades and modifications. This is an important problem for this industry with a large economy.

Conclusion

The results revealed that blasting angle influences surface wear, with lower angles being more efficient in paint removal on hard surfaces. Optimal paint removal was achieved by adjusting air pressure based on surface hardness, and nozzle diameter played an important role in both performance and process time.

Declaration of Ethical Standards

The authors of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

Design and Production of an Environmentally Friendly Cabin Type Full Automation Paint Removal Machine

(This study was presented at INERS 2024 conference.)

Research Article

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ABSTRACT

The effective and damage-free removal of deteriorated paint and varnish from wood surfaces is vital for both aesthetic and long-term material use. Traditional methods like scraping or sanding are labor-intensive and time-consuming. Moreover, alternative solutions like paint strippers pose significant threats to human health and the environment. To address these challenges, this study introduces a groundbreaking solution: The Cabin Type Full Automation Paint Removal Machine (CAPREM), designed and manufactured. The CAPREM is engineered to efficiently eliminate layers of paint and varnish from diverse materials, including wood, by blasting abrasive media onto the surface using compressed air. With the ability to control and adjust parameters such as air pressure, nozzle diameter, removal angle, removal distance, and feed rate, the machine offers flexibility for various coating layer removal scenarios. Furthermore, by enhancing the diversity of abrasive media, the CAPREM aims to provide an environmentally friendly solution for coating layer removal, benefiting multiple industries and advancing research in this field.

Keywords: Coating, paint removal, varnish, wood surfaces, media blasting.

Çevre Dostu Kabin Tipi Tam Otomasyon Boya Temizleme Makinesi Tasarımı ve Üretimi

ÖZ

Ahşap yüzeylerden bozulmuş boya ve verniğin etkili ve hasarsız bir şekilde çıkarılması hem estetik görünüm hem de uzun vadeli malzeme kullanımı açısından büyük önem taşımaktadır. Kazıma veya zımparalama gibi geleneksel yöntemler, yoğun emek gerektirmektedir ve uygulaması oldukça zaman alıcıdır. Bunun yanı sıra, boya sökücüler gibi alternatif çözümler, insan sağlığına ve çevreye ciddi tehditler oluşturmaktadır. Bu sorunlara çözüm getirmek amacıyla bu çalışma, yeni bir yöntem olarak Kabini Tipi Tam Otomasyon Boya Temizleme Makinesini (KATTABOT) tanıtmakta olup, bu cihazın tasarım ve imalat süreçlerini kapsamaktadır. KATTABOT, ahşap da dahil olmak üzere çeşitli malzemelerden boya ve vernik katmanlarını basınçlı hava ile aşındırıcı madde püskürterek etkili bir şekilde giderecek şekilde tasarlanmıştır. Hava basıncı, nozul çapı, temizleme açısı, mesafe ve ilerleme hızı gibi parametrelerin kontrol edilebilir ve ayarlanabilir olması sayesinde makine, farklı kaplama katmanlarını sökme senaryolarına esneklik sağlamaktadır. Ayrıca, aşındırıcı malzeme çeşitliliğini artırarak KATTABOT, kaplama katmanlarını gidermede çevre dostu bir çözüm sunmayı hedeflemekte, böylece çok sayıda sektöre fayda yaratmakta ve bu alandaki araştırmalara katkı sunmaktadır.

Anahtar kelimeler: Kaplama, boya kaldırma, vernik, ahşap yüzeyler, medya püskürtme

1. INTRODUCTION

Wood is a natural, organic, and biologically renewable raw material that can be directly sourced from nature. Due to its distinctive properties, it has applications in a wide range of engineering uses, including multi-story buildings, watercraft, spacecraft, and musical instruments [1-3]. Considering the variety of places where wood and wood-based materials will be used, it is necessary to protect them against the environmental effects they will encounter. To ensure long-term service and protection protection, a range of preservatives, paints, and varnishes are commonly utilized [4–6]. However, these preservatives may also lose their protective properties over time depending on external influences [7]. Removing and reapplying these aged layers that have lost their functionality is essential both for aesthetic reasons and to extend the life of the material [8].

Varnishes and paints adhere strongly to wood surfaces, and separating them from the surface is a challenging process [9]. The process of removing aged layers from wood materials requires a lot of labor and time [10]. Traditional abrasives, such as scrapers, wires, and sandpapers, are highly effective when used on small surfaces. However, these tools are often inefficient on large surfaces like structural elements or marine vessels [11]. Additionally, the layers on intricate and carved surfaces cannot be removed effectively through mechanical methods [12]. The use of chemical methods, another alternative, is being limited day by day because

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they contain volatile organic compounds (VOCs) and toxic wastes that have adverse effects on the environment and human health [13]. VOCs, although sometimes non-carbon-containing volatile compounds, are generally released into the atmosphere from sources such as fossil fuel combustion, industrial processes, paint, and coating applications, contributing to air pollution [14]. VOCs can trigger the formation of ozone and other pollutants in the atmosphere, leading to an indirect impact on climate change. Therefore, many countries and sectors address the control of VOC emissions while fulfilling their emission reduction commitments under the Paris Climate Agreement [15]. Similarly, the Kyoto Protocol is one of the first international agreements to establish binding targets for reducing emissions of specific greenhouse gases, including carbon dioxide, methane, nitrogen oxides, and certain fluorinated gases. Although VOCs are not among the greenhouse gases directly targeted by the Kyoto Protocol, they are indirectly linked to climate change due to their effects [16]. Therefore, the reduction of VOC usage has been established as a common goal for humanity, supported by these agreements.

As environmental awareness increases, studies on paint removal methods and machines that do not harm the environment or cause health problems are becoming more important. Recent advances have been made in the field of environmentally friendly paint removing, with tools such as organic or natural paint solvents, industrial sanding machines, and pressurized water jets [17–19]. These methods, however, are typically developed for specific applications and for limited number of materials. Due to this, it is of the utmost importance that any contributions made to the field of environmentally friendly paint removal are made. The paint removal process, which is carried out by spraying different types of media selected according to the properties of the surface to be processed with the help of compressed air, has a widespread use in different industries such aviation, marine vehicles, automotive [20]. Due to its ease of application, cost-effectiveness, selection of media suitable for different materials, and fast and effective removal of the paint layer from the material surface without damaging it, this method is very advantageous compared with other methods [21]. Paint removal machines and media commonly used in the industry are often optimized for hard surfaces such as metal, glass or concrete [19]. For this reason, these tools are not suitable for materials with different technical properties, such as wood. Although some parameters of existing machines for removing layers from surfaces by holding the blasting head (nozzle) free-handed can be adapted for wood materials, there is no machine that allows the control of effective parameters directly in this process. Considering that wood is a heterogeneous material which is used for many purposes, this is a significant disadvantage. Also, the existing machines are operator-dependent, resulting in differences. Therefore, there is a serious need for machines that can control the parameters automatically. The elimination of this deficiency in the industry can be considered a contribution to both the literature and the finishing and woodworking industries.

This study describes the design and manufacture of a machine that can remove aged layers on wood and wooden surfaces. This machine, unlike its counterparts described above, allows the operator to adjust the air pressure, nozzle bore diameter, blast angle, blast distance, and feed speed of the nozzle independently and automatically. As a result of these characteristics, it also can use both industrially manufactured blasting media as well as other blasting media that can be used as an alternative. In this manner, this study is expected to make a significant contribution to both the paint removal industry and research efforts in this area.

2. CURRENT TECHNOLOGIES IN PRESSURIZED SYSTEMS

The process of layer removal with pressurized systems can be defined as the application of various media of different sizes, either in dry form or mixed with certain liquids, being sprayed onto the surface using compressed air. There are a number of variables that play a significant role in the effective removal of the layers from a surface, including the structure of the medium used, the pressure of the air, and the type of nozzle used [22,23]. The use of this method began in the early 1990s to remove paint from composite surfaces commonly used in aircraft construction. It has emerged as a viable alternative to chemical paint removal processes to eliminate problems associated with chemicals and to improve the efficiency of the working environment [24, 25]. This machine is available in two different types: the mobile type (open system) and the cabin type (closed system).

Mobile type machines are a general name given to portable machines (Figure 1). These machines are equipped with tanks that contain abrasive media which is then sprayed onto surfaces by compressed air [26].

Figure 1. Portable machines and its operation [27].

Because these machines are portable, no fixed apparatus is required to strip paint, and the paint-stripping process can be carried out anywhere. The sprayed media and the

removed layers can, however, be dispersed into the air as particles during the use of these machines, which will cause the working environment to be filled with harmful contaminants [21,28]. Therefore, it is important to wear protective equipment during the blasting operation and to ensure that the environment is well ventilated. Additionally, the high level of noise produced by these machines may adversely affect the hearing health of workers [29]. It is important to note that the operator is fully responsible for managing the all the process. As a result, depending on the skill level of the operator, there Is a high risk of deformation on surfaces that require precision operations. In addition, standardized results are not always achievable due to the difficulties involved in the process.

Cabin type machines have a closed cabin that collects dust and paint residues released during the process inside the machine, and the paint removing process takes place here (Figure 2). By eliminating dust and paint residues, the working environment is kept clean, and the operator's health is protected [30]. Nonetheless, the free-hand operation of the operator, similar to that of mobile type machines, is a problem that requires a solution [31]. Otherwise, it may be difficult to prepare the surface for subsequent finishing operations if surfaces are damaged or the blast medium is embedded in the surface.

Figure 2. A cabin-type machine and its operation [27]

3. CABIN-TYPE FULL AUTOMATION PAINT REMOVAL MACHINE (CAPREM)

This study focuses on the design and manufacture of an automated paint removal machine in the cabin-type that can be used to remove aged protective layers automatically (Fig. 3-4). The machine was modeled and simulated using SolidWorks and Sketch Up 3D CAD software. As a result of this process, possible production problems were identified at the design stage and solutions developed. Considering the commercial potential of the machine, its name was determined as "CAPREM", which is the acronym of the term "Cabin-Type Full Automation Paint Removal Machine".

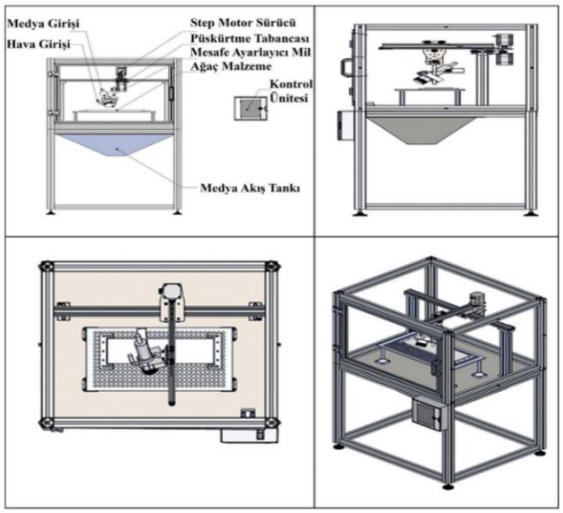

Figure 3. The design of the CAPREM

The CAPREM, which can perform the paint removing process with the help of a nozzle that can move in 3 axes in a closed cabin, enables the alteration all parameters affecting the process. Based on the characteristics of the medium being blasted and the layer being removed, the CAPREM allows for the adjustment of parameters such as pressure, angle, distance, and feed rate.

Figure 4. The CAPREM and auxiliary equipment

The use of high-density media, such as iron balls, silica, and glass spheres, in paint removal processes can cause damage to the surfaces of low-density heterogeneous materials like wood. Consequently, the anticipated performance in layer removal process may not be achieved [33]. Especially fine particles like silica can readily disperse into the air, potentially leading to enduring and severe health issues, including the development of silicosis [34–36]. The purpose of the CAPREM is to reduce the use of chemicals that threaten human and environmental health, as well as to bring agricultural wastes back to the industry as blasting media that provide economic and environmental benefits. Although the CAPREM was initially conceived for the purpose of removing old paint layers from wooden surfaces, its infrastructure is versatile and adaptable for use on various materials, including plastic, metal, and more. As a result, it is expected to have a broad spectrum of applications.

3.1. Working Principle

The CAPREM removes the old protective layers from the surfaces by spraying abrasive medium which stored in the tank at the desired angle, distance, pressure, and feed rate. Aside from the air pressure, the angle of the nozzle, its distance from the surface, and the feed rate are the primary parameters that significantly impact the outcome of layer removal using pressurized systems [23]. Previous studies have reported that these parameters have a substantial impact on the color, gloss, and surface roughness values of processed surfaces [37–39]. With the correct selection of these parameters, it is thought that the preparation process for the re-finishing process to be applied after the paint removal process will be shortened. The distinctive aspects of the CAPREM in comparison to its industrial counterparts are presented in the subsequent section under distinct headings.

3.1.1. Adjustable blasting angle

The layer-removal process is carried out freehand in both types of machines used in industry. The result of this is that the paint cannot be removed uniformly, and the results vary depending on the operator. Different studies show that surface properties change depending on the blasting angle [39–41]. With the CAPREM, the nozzle can be adjusted at any angle desired, unlike its counterparts. This feature makes it possible to determine the most effective angle for removing paint from surfaces with different characteristics (Figure 5).

Figure 5. Adjustment unit for blasting angles and its use.

3.1.2. Adjustable blasting distance

During paint removal, the distance between the nozzle and the surface to be treated is vital to ensuring that the sprayed media reaches the entire surface and transferring the maximum amount of energy. With decreasing distances between the nozzle and the surface, media is hit on a larger area, but the effective working area becomes smaller. Therefore, it is essential that the blasting distance is adjustable to allow paint removal to be carried out over a large area [37-38]. The CAPREM is equipped with stepper motors that have high drive power, allowing paint removal to be performed easily on different axes (Figure 6). It is possible to realize an effective paint removal process at the desired distance by using the linear motion created by these motors.

3.1.3. Adjustable feed rate

To control the feed rate and automatically start and end the paint removal process, a universal G-code sender is used.

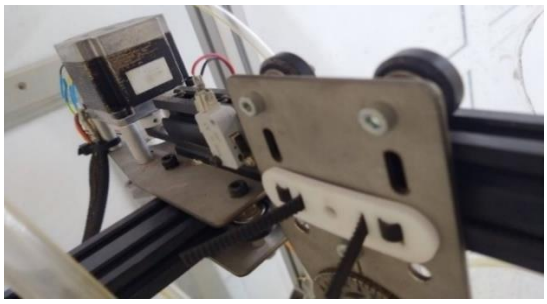

Figure 6. Stepper motors and drive system

The G-code sender provides an interface to the code interpreter machine that it communicates with via the universal serial bus. The G-code sender sends coordinate codes to the code interpreter machine with which it communicates via the universal serial bus, providing an interface to manage it. Thanks to this interface, the accuracy of the G-codes and the speed of the process can be controlled. Through this interface, it is also possible to monitor the operation of the machine and to intervene at any time during the process. The universal G-code transmitter used in the CAPREM is open source, replacing the physical control panel and enabling wired or wireless operation via computers or mobile devices.

3.1.4. Sample fixing clamps

The paint removal process is carried out by placing the material in a fixed position. The fixing clamps, which can be adjusted at desired distances according to the size of the sample, are designed to move on a perforated sheet plate. These clamps make it possible to remove paint from samples of varying sizes and shapes (Figure 7). Furthermore, CARPEM has the infrastructure in place for the use of different types of clamps for various material geometries.

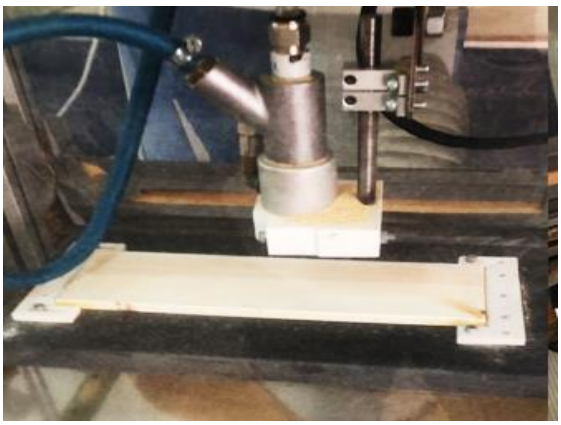

Figure 7. Fixing clamps and its use.

3.2. Dust Collection System

Dust collectors are designed to gather dust and particles using a vacuum system and store them in a hopper for future use or disposal. Typically, these systems find applications in various industries such as construction, machining, and workplaces with high concentrations of dust. One of the primary challenges in removing paint from surfaces using pressurized systems is the generation

of dust and particles. These not only degrade the quality of the working environment but also pose environmental and health hazards. To mitigate the formation of dust and particles in the environment, the CAPREM system is designed as a closed cabin type. To achieve this, the CAPREM is equipped with a dust extraction and collection system, which captures all particles generated during the process in a separate chamber. These collected particles can then be reused in subsequent processes.

4. PRELIMINARY STUDIES AND EVALUATION

The performance of the CAPREM was evaluated by preliminary studies carried out on samples (Figure 8).

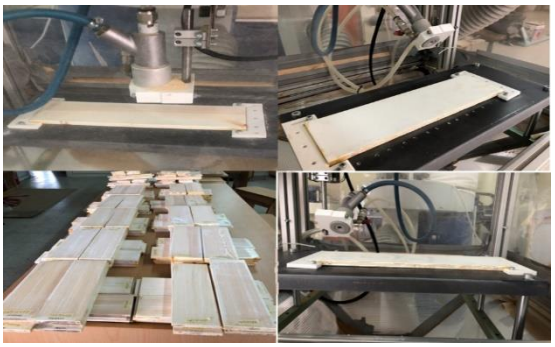

Figure 8. Preliminary Studies

In preliminary studies, paint removal process was carried out at different parameters on the surfaces using different media and the color, gloss, hardness, surface wear amount, surface roughness and contact angle properties of these surfaces were examined. The paint removal process was investigated at both different parameters and with different abrasive media in preliminary studies. The treated surfaces were evaluated for color, gloss, hardness, wear amount, roughness, and contact angle properties. Based on the results of the analysis, different parameters and different types of abrasive media had different levels of impact on the surface properties of the samples.

It was determined that blasting angle affects how much wear occurs on the surface, and that as the angle decreases, the efficiency of the removal process decreases, although less deformation occurs on the surface. Another observation obtained from the preliminary tests in the study is that 90 degrees or close angles perform more effective paint removal, especially on hard surfaces.

Based on the results of the study, the paint could be removed without damaging the surfaces when high pressure was used for hard surfaces and low pressure for soft surfaces. The higher the air pressure used to apply the media onto the surface, the more effectively the paint is removed. On the other hand, it was found that too high air pressures can cause severe deformation, especially in soft wood tissues.

With an increasing nozzle diameter, paint removal performance decreased, while process time was shortened. This is because the relationship between pressure and nozzle diameter affects the kinetic energy of the abrasive media. As a result, it has been determined that different combinations of pressure and nozzle diameter should be used on different surfaces. It has been observed that the CAPREM, thanks to its technical infrastructure, can provide the opportunity to apply these combinations across a wide range. In addition, it was found that as the blasting distance decreased, the media had a greater impact on the surface. Conversely, as the blasting distance increases, the amount of paint removed per unit time increases. Therefore, it is important to choose the removing distance according to the material and medium to save processing time and achieve better results.

5. CONCLUSION

In terms of the ability to remove paint from wood and wooden surfaces, the CAPREM is an industrial solution with considerable potential. It is capable of removing layers of paint and varnish from a wide variety of materials including metal, plastic, stone, not just wooden surfaces. Especially when it comes to the removal of aged protective layers on surfaces with heterogeneous properties, such as wood materials, the capability to adjust various parameters could address a significant need in the field.

Additionally, other factors that enhance the potential of the CAPREM include its compatibility with abrasive medium of various characteristics and the fact that the removing process with it does not negatively impact the environment or human health. Hence, this machine holds the potential to provide substantial opportunities not only for researchers and paint manufacturers but also for numerous sectors, including the furniture and decoration industry. Advancements, such as integrations with image processing technologies and cyclonic dust extractors, can further augment the capability to provide cleaner, more precise, and environmentally friendly paint removing solutions.

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DECLARATION OF ETHICAL STANDARDS

The author(s) of this article declare that the materials and methods used in their studies do not require ethics committee approval and/or legal-specific permission.

AUTHORS' CONTRIBUTIONS

Mustafa KORKMAZ: Contributed to the design, manufacturing, and testing of the machine presented in this study and participated in the writing of the manuscript.

Mehmet BUDAKÇI: Contributed to the design, manufacturing, and testing of the machine presented in this study and participated in the writing of the manuscript.

İzham KILINÇ: Contributed to the design, manufacturing, and testing of the machine presented in this study and participated in the writing of the manuscript.

CONFLICT OF INTEREST

There is no conflict of interest in this study.

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