Study of a Cutting Fluid Application System Adaptation on a Bench Milling Machine for an Academic Laboratory Environment

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Abstract: Cutting fluid is a resource that can benefit machining, improving the service life, surface, and dimensional qualities of cutting tools. For the operation of a basic cutting fluid application system, it is necessary to consider the components that store, filter, and induce the flow of the cutting fluid. Some essential components are the reservoir, the filter, and the pump. Aiming to provide better machining conditions, this study presented the proposal for designing and manufacturing a cutting fluid application system for an academic laboratory's bench drill/milling machine. The experimental research characterized the study methodology, in which the system was built with the least possible resources. The main result showed that the system achieved the proposed objective. For pump selection, a system of equations was developed in Microsoft Excel software, which indicated a pressure variation in the flow system of approximately 15 kPa. After the three-dimensional modeling, a script for the manufacture and assembly of the system components was prepared, involving the processes of forming, machining and welding. Adaptations were made to the machine tool, such as the insertion of a limit switch that reduced the longitudinal displacement of the work table by 150 mm. An electronic command system was inserted to control the cutting fluid flow. In the testing phase, positive aspects were observed (reservoir position, absence of leaks, cutting fluid flow, among others) and negative aspects (cutting fluid return paths). Some further improvements proved possible, especially on a machine not designed to have a cutting fluid system.

Keywords: Cutting fluid, Manufacturing processes, Chip, Machine tool, Three-dimensional modeling, Reservoir, Numerical method.

1. INTRODUCTION

In machining processes, cutting fluid application is essential not only to facilitate chip removal or breakage but also to reduce tool wear, balance the machining temperature, protect the workpiece and the machine against the corrosion process, and to ensure the dimensional and surface quality of the machined part [1]. As for cutting speed, the fluid has two functions: (1) lubrication at low speeds and (2) cooling at high speeds [2]. In 1, the fluid penetrates the workpiece/tool interface, forming a protective film that reduces the coefficient of friction, reducing the magnitude of the abrasion and adhesion mechanisms, which, later, can lead to the appearance of the built-up cutting edge (BUE). In 2, penetration at this interface is inefficient due to the high cutting speed, so it is important that the fluid can dissipate as much heat as possible to reduce possible wear related to abrasion, adhesion, and diffusion [3].

The cutting fluid can be defined as a chemical compound, usually in the liquid or gaseous state, used as input in the cutting process. Although the liquid state is the most used option in processes in general. In the liquid state, cutting fluids can be classified as: integral, emulsion, synthetic and semi-synthetic, the last three being soluble [3].

The cutting fluid choice is critical and has a substantial effect. Its selection varies according to machining conditions and processes, directly affecting productivity, cutting tool life, and production cost [4].

The integral cutting fluid consists of mineral, vegetable, or animal oil with or without additives [5]. It is recommended for high-cutting stress conditions at low cutting speeds [3, 4].

The emulsion is a mixture of whole oil in water [5], which is achieved in the presence of emulsifiers. Generally prepared in proportions between 1/10 to 1/100 (oil/water), the emulsions combine the lubricating and anti-corrosive properties of oils with the excellent cooling properties of water [3, 4]. Conventional

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emulsions have a milky appearance, but they can be translucent for specific applications. These have a higher emulsifier/oil ratio which reduces the size of the oil droplet, thus increasing its clarity [6].

The synthetic fluid consists of water-soluble chemical substances, organic and inorganic salts, lubricity additives, biocides, corrosion inhibitors, and without mineral oil [7]. Features good heat dissipation (cooling characteristic), service life, detergent, antioxidant, and anti-corrosion ability [3, 4]. Synthetic cutting fluid is a good coolant but it provides insufficient lubrication compared to other cutting fluids due to lack of oiliness [7].

Semi-synthetic fluid is a combination of synthetic fluid and emulsion [7]. The lower amount of mineral oil and the presence of biocides increase fluid life and reduce health risks. The advantages and limitations are like synthetic fluids, except that semi-synthetics have better lubricity [3, 4].

The appropriate choice of a cutting fluid must fall back on one with the correct chemical formulation and properties to tackle the adversities of a specific cutting process. Of primary concern are machinability of the material, compatibility (metallurgical, chemical and human) and acceptability (fluid properties, reliability and stability) [8]. It must be applied using a method that allows it to get as close as possible to the cutting edge within the chip-tool interface to perform its functions properly. The main techniques for applying cutting fluid are low-pressure jetting, spraying (MQL), and high-pressure system.

Low-pressure jetting is a widely used technique due to its simplicity, but it has been replaced by others that use less cutting fluid, given the environmental and unhealthy impacts. The flow rate usually varies between 10 L/min and 225 L/min. This method is generally available on conventional machine tools and CNC machining centers. The cutting fluid flow is directed to the cutting tool and chip surface via a nozzle [4].

The MQL technique is a small amount of lubricating oil mixed with a compressed air stream, forming a mist of ultrafine drops projected to the cutting region. Fluid flow can vary from 10 to 20 mL/h with compressed air at high velocity (100 ms^{-1}) [4]. MQL technology promotes evaporative and convective heat transfer thus produces efective cooling as compared to wet cooling [9]. This technique's main benefits are surface quality, better cutting operations performance, and reduced environmental impact [4].

The high-pressure technique is applied in more technologically advanced processes for hard machining materials or at high cutting speeds to increase the life of cutting tools and improve chip breaking. A jet of cutting fluid at high pressure (range of 5.5 – 35 MPa) is directed at the chip-tool interface through internal channels (jet cut) present in the cutting tool [10].

To operate a basic cutting fluid application system, it is necessary to consider components that store, filter, and induce the flow of cutting fluid. These must be designed for the satisfactory operation of the system, avoiding insufficient flow, contamination, restrictions in the discharge and return lines, and the waste of cutting fluid. Some essential components can be considered, such as the reservoir, the pump, and the filter [11].

The reservoir is one of the essential components whose primary function is to contain fluid until it is used. It also acts as a heat exchanger and impurity separator, and, in some cases, it can support fixing the pump and drive motor. It must resist corrosion due to the storage of different lubricants. Its sizing considers a sizing according to the need of the application. It is important to meet the minimum and maximum needs of the system [12].

The pump is the component responsible for transporting the cutting fluid to its destination: the machining area. Pump selection is a function of flow and system pressure [12].

When cutting fluid is used, impurities, including fine chips, grinding wheel particles, dirt, scale from workpieces and sand from castings, will inevitably be mixed [8]. In the absence of filtration of the cutting fluid, impurities return to the reservoir, reducing the useful life of the pump, the cutting tool, and the cutting fluid itself [13]. The filter is a device that retains all insoluble contaminants from a fluid, is usually employed to separate solid particles from liquids [14]. It is classified into two types: chemical and mechanical. The mechanical filter is formed by one or more meshes that prevent passing particles with dimensions larger than their pores [13]. Filter elements are divided into depth and surface elements. In surface elements, usually in the form of wire mesh or perforated metal, a fluid flow has a direct path through a material layer in which impurities are trapped on the element's surface [13].

This study aimed to design, manufacture and validate a cutting fluid application system for a bench drill/milling machine, developing a system that offers constant cutting fluid applicability with minimal operator intervention and provides improvements in conditions of use. of the academic laboratory. For this, the characteristics of the cutting fluid used in the system were studied, considering the type of application (machining for didactic purposes) and the work environment conditions. The operating parameters of the system were also studied according to the conditions of use of the machine tool (reservoir volume, flow rate, and fluid flow pressure).

The study was motivated by the opportunity for improvements observed in the academic laboratory's machine, in which practical machining classes are carried out with the application of cutting fluid via an oil can [12]. On some occasions, it was necessary and safer to divide the functions between the practitioners of the practical classes, one to operate the machine tool and the other to apply the cutting fluid. Since most are practitioners with little or no experience, the risk of accidents during these practices becomes greater. Also, for machining operations that are performed with high-speed steel tools, consistent application of cutting fluid can provide better surface finish results and ensure proper lubrication and cooling to increase tool life [3].

The novelty of this study lies in the creation and implementation of the system in a machine tool, which differs from other studies that generally address reviews and investigations on the influences of cutting fluids on machining processes.

2. MATERIALS AND METHODS

This study was carried out through an experimental method, with the purpose of practical application in an academic laboratory of mechanical machining (Centro Universitário UNA, Belo Horizonte, Brazil). The theoretical basis and information obtained in the mechanical environment, or "factory floor," enabled the construction of a prototype that, after its validation, would meet the proposed objective. In analogy to the phases of developing a project/product and to avoid possible loss of time and cost due to rework, three-dimensional modeling [12] in software was used to design the cutting fluid application system. Much of the system, such as the fluid reservoir and other fastening parts, was manufactured from standardized materials (rectangular and round plates and bars and angles) of commercial steel (Sucal Ferro e Aço, Belo Horizonte, Brazil). Permanent union processes (welding with coated electrode and MIG) and non-permanent union (fixation by screws and nuts) were used. To avoid oxidation, all components subject to contact with the fluid were coated with Hammerite synthetic enamel (Clube da Casa Gorgulho, São Lourenço, Brazil), silver color, code 5202877, composed of aluminum paste, cobalt hydroxide, calcium octoate, and mineral turpentine.

To test the system, ME-I Quimatic Tapmatic semi-synthetic soluble oil was used as cutting fluid, with a ratio of 19 parts of water to 1 part of concentrate, recommended by the manufacturer for general applications and all types of metals. This choice was due to its availability at the location where the study was carried out. It consequently favored the cost reduction of the project. The cutting fluid was applied in machining using the low-pressure jetting technique, as it is an academic environment in which machining operations are not extensive and generally present low cutting speeds compared to machining processes in industries where make fair MQL and high-pressure jetting techniques [3].

For the validation of the proposed system, tests were carried out in conventional milling operations with the application of cutting fluid, observing the behavior of the flow of the spout and the return to the reservoir. The pump flow rate has been adjusted in such a way that the cutting fluid is not spread excessively, which would result in too much waste and splash in the working environment. Furthermore, the return flow should be as good as possible, as the high restriction would cause a rapid emptying of the reservoir, drastically reducing the system's operating time.

2.1. Elaboration of the Cutting Fluid Application System in Three-Dimensional Modeling

In this study, the proposed system was designed and manufactured for the Manrod benchtop drill/mill, model ZX-40/PC MR-205, located in an academic laboratory of mechanical machining. This machine tool is recommended for professional use, has six rotation speeds (120 to 1970 rpm), and has maximum capabilities in drilling, face milling, and end milling operations with diameters of 45 mm, 80 mm, and 28 mm, respectively. It has a nominal power of 1.1 kW and is energized with a three-phase alternating voltage of 220 V at 60 Hz.

Initially, it was necessary to know the main dimensions of the machine tool, which were measured with two conventional measuring instruments: a universal caliper and a manual tape measure. Initially, for three-dimensional modeling, the following were considered, among others:

- Machine tool base dimensions: 395 mm x 595 mm x 595 mm;
- Dimensions of the worktop plate: 566 mm x 766 mm;
- Column height: 870 mm;
- Tailstock vertical displacement: 300 mm;
- Horizontal displacement of the table: 320 mm;
- Transverse displacement of the table: 150 mm;

To adapt the cutting fluid application system, an ideal place for fixing the cutting fluid reservoir that would affect the operator's work area as little as possible was analyzed to provide the least ergonomic loss of use of the machine tool. After this analysis, the fixation in the lower posterior part was chosen, as shown in Figure **1**. In this three-dimensional model, the main functional components were considered [12] necessary for the circulation of the cutting fluid: the reservoir, the discharge and return pipes, and the return holes present in the machine tool table.

To guarantee the functionality of the movements of the tailstock and the machine-tool coordinate table, the discharge and return hoses, presented in Figure **1**, was projected in the model in the form of flexible tubing (hose) using the "Routing" feature of the software. In this way, it was possible to visualize and estimate the real deformation behavior of flexible tubes during vertical, horizontal, and transverse displacements performed in drilling and milling processes (Figure **2**).

2.2. Sizing the Cutting Fluid Reservoir

The reservoir dimensioning followed as much as possible the recommendations provided for the study development, limited to some boundary conditions (resources) of the project. As presented in Figure **3**, it is a non-pressurized reservoir with a capacity of 18 liters. There is a distance of approximately 150 mm between the bottom of the tank and the ground. The stored fluid volume was sized to supply the system for at least 3 minutes before returning to the reservoir. A baffle, with a height equivalent to 2/3 of the fluid level, was inserted to fix the pump, avoid the turbulence of the cutting fluid, increase the heat dissipation of the

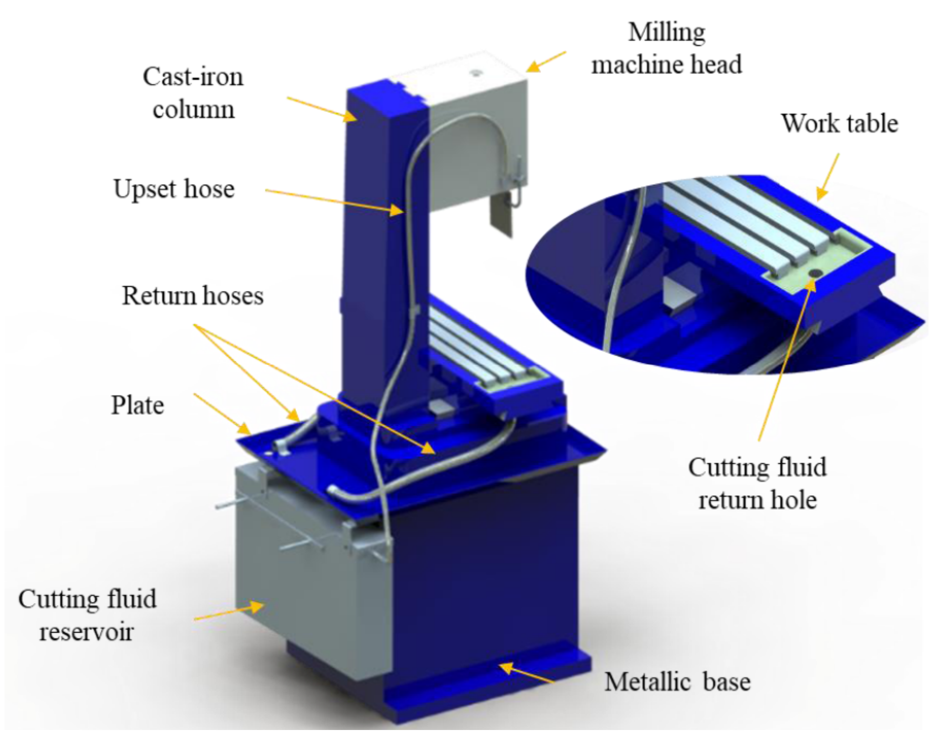

Figure 1: Illustration of the three-dimensional modeling of the main components of the cutting fluid application system arranged in the machine tool.

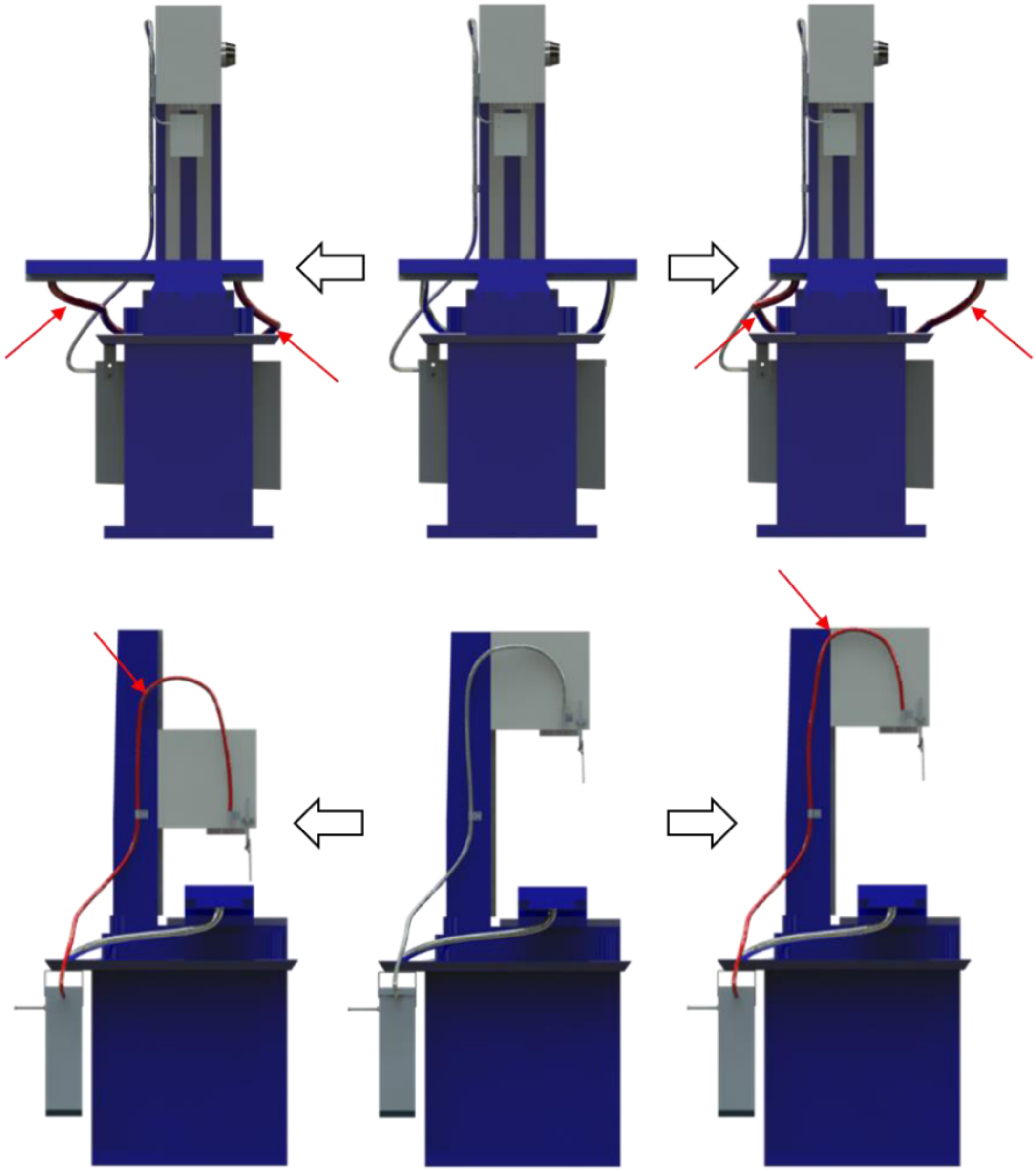

Figure 2: Illustration of the deformation of the flexible tubes that occurred during the vertical and horizontal displacements of machining coordinates present in the machine tool.

reservoir and help the settling of impurities at the bottom. To direct impurities closer to the drain hole, the bottom of the reservoir has a 2º inclination, similar to the methodology used by Lima Menezes *et al*. [2], whose purpose was to separate impurities from the cutting fluid. The cap keeps the fluid isolated from the external environment to minimize the formation of bacteria [5]. When the system is used, the operator must remove it to allow the return of the cutting fluid, which flows through the return hoses connected to the milling table, whose terminals are fixed on the plate (or bench) of the machine tool (Figure **4**).

Fixed in the reservoir (see Figure **3** and Figure **4**), the cutting fluid filter element is a galvanized metal mesh with a wire diameter of 0.30 mm and a mesh opening of 1.4 mm, acting as a return filter. The mesh is attached to filter support, which was manufactured with an angle bracket and a flat bar. Utilizing handles, the operator can remove and insert the filter, similar to handling a drawer (Figure **3**). The filter option in the return line proved to be more suitable for the development of the system due to the ease of installation, maintenance, and simplicity of construction. In addition, the mesh is easily replaceable

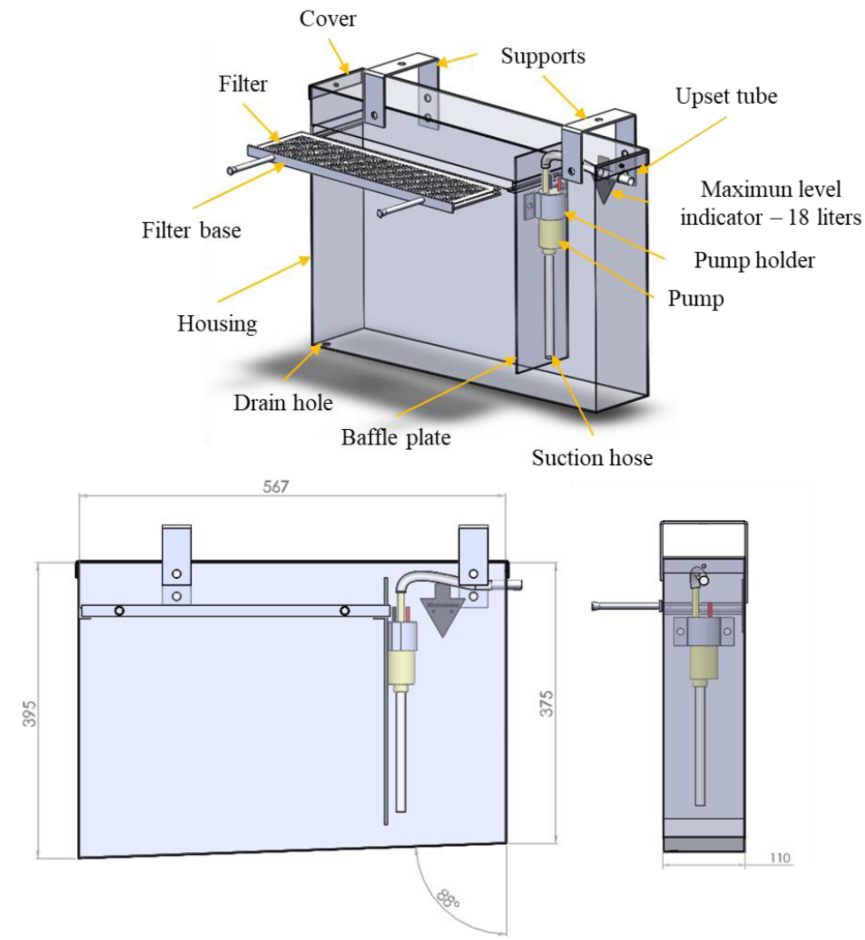

Figure 3: Illustration of constituent parts and components present in the cutting fluid reservoir.

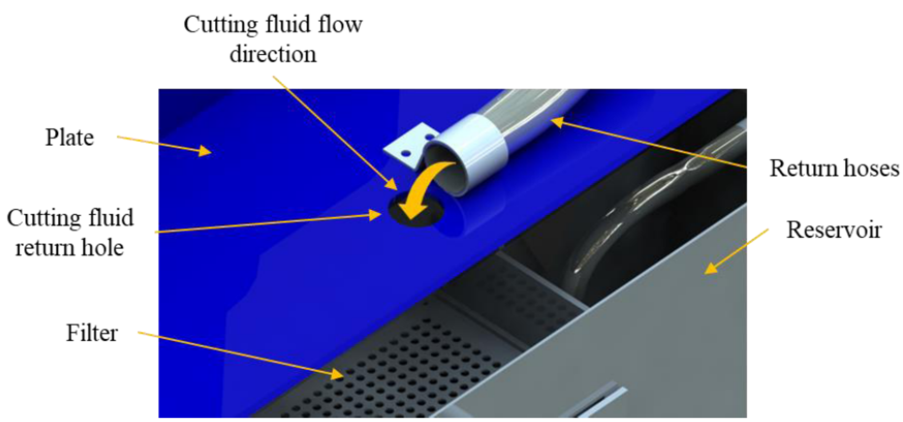

Figure 4: Illustration of the flexible return piping terminal, fixed on the workbench plate, for the return flow of the cutting fluid to the reservoir.

or mostly reusable, with only periodic cleaning required [13].

2.3. Pumping the Cutting Fluid in the System

Circulation of the cutting fluid was performed using an external electrical pump Bosh model GM 06443268/VCH032 (Action Racing, Belo Horizonte, Brazil), a pressure of 2.5 bar and flow rate of 115 L/h (Figure **5**, generally applied in the fuel supply system of internal combustion engines of automobiles. This choice was established due to the affordable acquisition cost and the considerably small cutting fluid application system size. Pump selection was carried

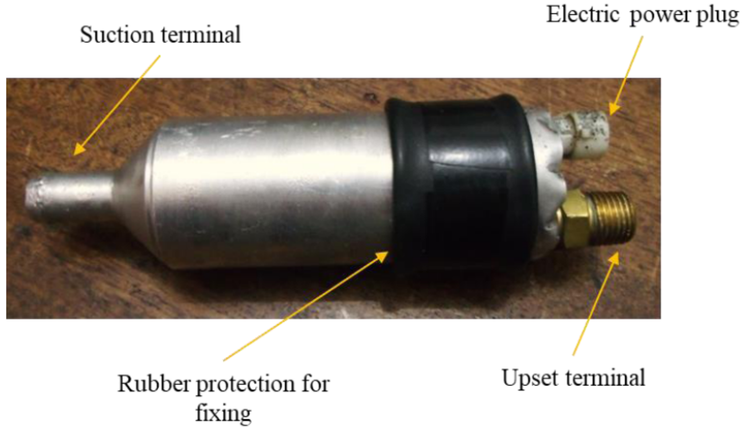

Figure 5: Bosch external electric pump, model GM 06443268/VCH 032.

out with the aid of an application developed in Microsoft Excel software [15], with the addition of the Solver add-in feature [16].

The application was designed to solve a type of problem observed in piping systems for flow: determining the pressure variation and pressure drop when the system's length, diameter, and flow are specified [17]. The numerical method present in the application was elaborated through the interaction of the following fundamental equations: (1) energy conservation, (2) volumetric flow, (3) Reynolds number, (4) Colebrook friction factor, and (5) loss total load of a drainage system. The respective equations are presented:

$$\frac{P_1}{\rho g} + \alpha_1 \frac{V_1^2}{2g} + z_1 = \frac{P_2}{\rho g} + \alpha_2 \frac{V_2^2}{2g} + z_2 + h_L \quad (m) \tag{1}$$

$$\dot{V} = \frac{V_{average} \pi D^2}{4} \quad (m^3/s) \tag{2}$$

$$R_e = \frac{V_{average} D}{\nu} = \frac{\rho V_{average} D}{\mu} \quad (dimensionless) \tag{3}$$

$$\frac{1}{\sqrt{f_{friction}}} = -2{,}0 log\left(\frac{\varepsilon/D}{3{,}7} + \frac{2{,}51}{R_e\sqrt{f_{friction}}}\right) \quad (dimensionless) \tag{4}$$

$$h_L = \left(f_{friction}\frac{L}{D} + \sum K_L\right)\frac{{V_{average}}^2}{2g} \quad (m) \tag{5}$$

The application was used following assumptions and entering the requested information:

- The flow is incompressible, turbulent (No. Reynolds ≥ 4000), and permanent;
- There is no heat transfer in the flow;
- The diameter of the pipe is constant;
- Pressures are given as manometric;
- Gravitational acceleration is 9.807 m/s^2;
- The pipe is between a starting point 1 (P_1, z_1) and final 2 (P_2, z_2) (Figure **6**);
- Reference point 1 (P_1, z_1) was given at the pump outlet, in the direction of flow, and point 2 (P_2, z_2) at the maximum height of the pipe (Figure **6**) [18];
- Internal pipe diameter: 12.7 mm, as specified in the pump catalog;
- Total straight pipe length: 2 m;
- The roughness of tube material: 0.01 mm [17];
- Working fluid: water;
- A specific mass of working fluid: 1000 kg/m^3;
- Dynamic viscosity of working fluid: 8.5×10^{-4} kg/(m.s);
- Flow system flow: 0.03 L/s;
- Static height of the flow system: 1.5 m, measured in three-dimensional modeling;
- Accessories present in the flow system: one (1) globe valve, two (2) 90° curves, and one (1) 180° curve.

For the cutting fluid application during machining operations, it was essential to consider that the machine tool operator should have the convenience of adjusting the fluid flow as desired. Thus, an electrical system was designed to control the intensity of the

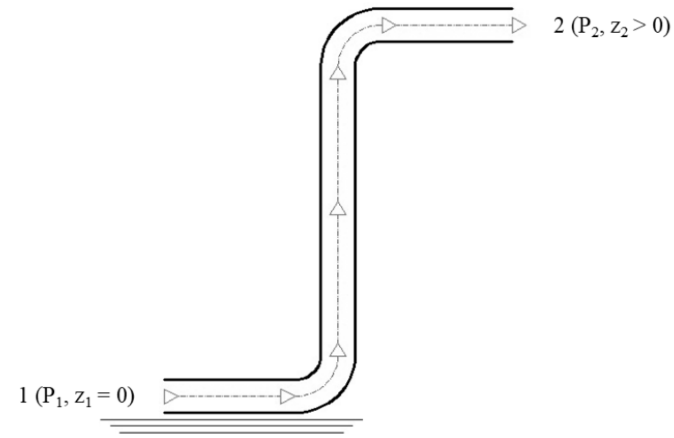

Figure 6: Illustrative and simplified scheme of the flow system, containing the flow direction of the working fluid and the reference points 1 and 2 with their respective values of height z.

electrical current supplied to the pump. As shown in the electrical diagram (Figure **7**), the system starts with an alternating voltage transformer (220 volts) for continuous (12 volts), whose purpose is to provide electricity to the other components. An ON/OFF switch (switch), driven by the machine tool operator, commands the low current circuit of the auxiliary circuit, which is responsible for providing electricity to the PWM controller [18, 19]. In this controller, the operator can adjust the flow of cutting fluid from 0 to 100% using a pot after energizing (ON switch).

3. RESULTS AND DISCUSSION

3.1. Determination of System Pressure Variation for Pump Validation

With the equations presented in the previous topic (Pumping of cutting fluid in the system), a system of equations was formulated to solve the objective problem [20]: determine the pressure variation of the flow system as shown below.

$$\begin{bmatrix} \sqrt{f_{friction}}\, log\left(a + \frac{2,51}{R_e\sqrt{f_{friction}}}\right) = -0,5 \\ R_e = b \\ V_{average} = c \\ h_L = f d V_{average}{}^2 \\ \Delta P = (e + h_L)\rho g \end{bmatrix}$$

$$\begin{cases} a = \varepsilon/D \\ b = \rho\,\dot{V}\,4/\pi D\mu \\ c = \dot{V}\,4/\pi D \\ d = (L_T/D2g) + k_L \\ e = z_2 + z_1 \end{cases} \quad (6)$$

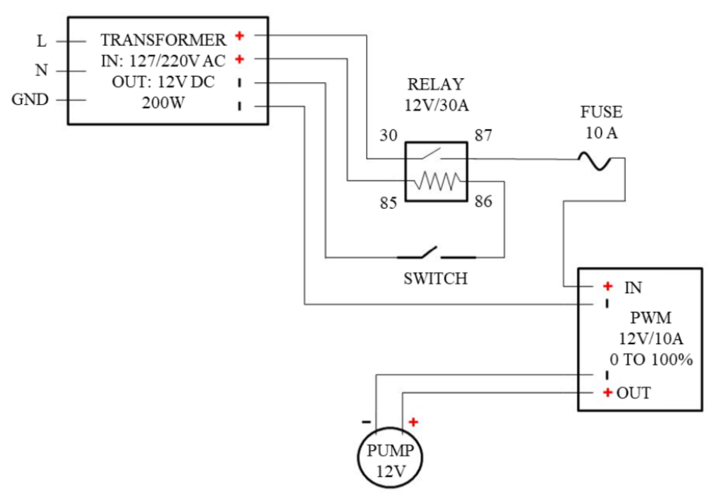

Figure 7: Illustration of the electrical diagram designed to drive the pump and control the cutting fluid flow.

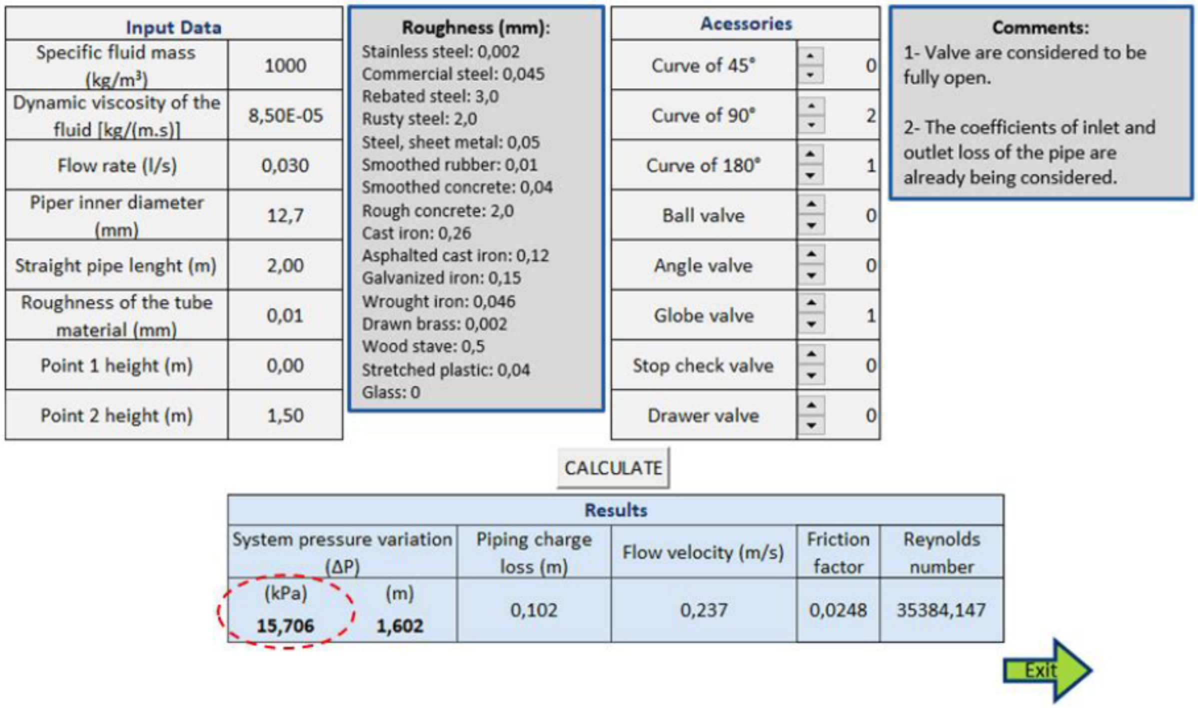

Figure 8: Illustration of flow system troubleshooting application data and results interface.

In the software, the Solver add-in aims to find the values for variables that meet all the constraints of the mathematical model [20] and that can also minimize or maximize the value of a function [16], using the GRG (Generalized Reduced Gradient) numerical method [21]. The system performs interactions using one-dimensional research through a variation of Newton's method [22]. As a result (Figure **8**), the application presented a pressure variation of approximately 15 kPa, a value below those presented in the pump catalog (100 to 300 kPa). Thus, the selected pump would meet the cutting fluid application system according to the pressure criterion.

3.2. Manufacture and Assembly of the Cutting Fluid Application System

After the three-dimensional modeling of all components of the cutting fluid application system, a manufacturing route was designed to avoid rework and additional material expenses. Conventional measuring instruments drew several reference lines for cutting, folding, and centering holes. The main manufacturing steps of the structural components are illustrated in Figure **9**. After tracing and cutting the sheet metal, the reservoir housing obtained an initial shape by forming process (folding). Then, rectangular and round profile bars were used to manufacture the filter base, with cutting and welding processes. A sheet metal part was welded to the inner part of the reservoir housing, and its position was referenced through the filter base. Cutting, folding, and drilling processes were used to manufacture the reservoir fixing brackets. The reservoir was manufactured by inserting, using welding, the front plate, in which a tear was machined to allow the filter to be plugged in. The lid of the reservoir, made of sheet metal, was inserted shortly after that. Finally, the cutting fluid reservoir was mounted on the machine tool.

The next stage of fabrication and assembly of the cutting fluid application system was related to the adaptations necessary to adapt the machine tool to the already manufactured components. These adaptations are summarized in Figure **10**. First, two holes 16 mm in diameter were machined, each one at the end of the worktable. In these holes, metallic tubes were inserted by interference, which fixed the return hoses. At the free ends of the hoses, the return terminals were inserted, whose purpose was to fix the correct projection position of the cutting fluid, in return, to the reservoir filter. To prevent the longitudinal course of the worktable from damaging the return tubes, it was necessary to adapt a new limit switch using a flat rectangular bar, which resulted in a total reduction of 150 mm (half to the right and the other half to the left).

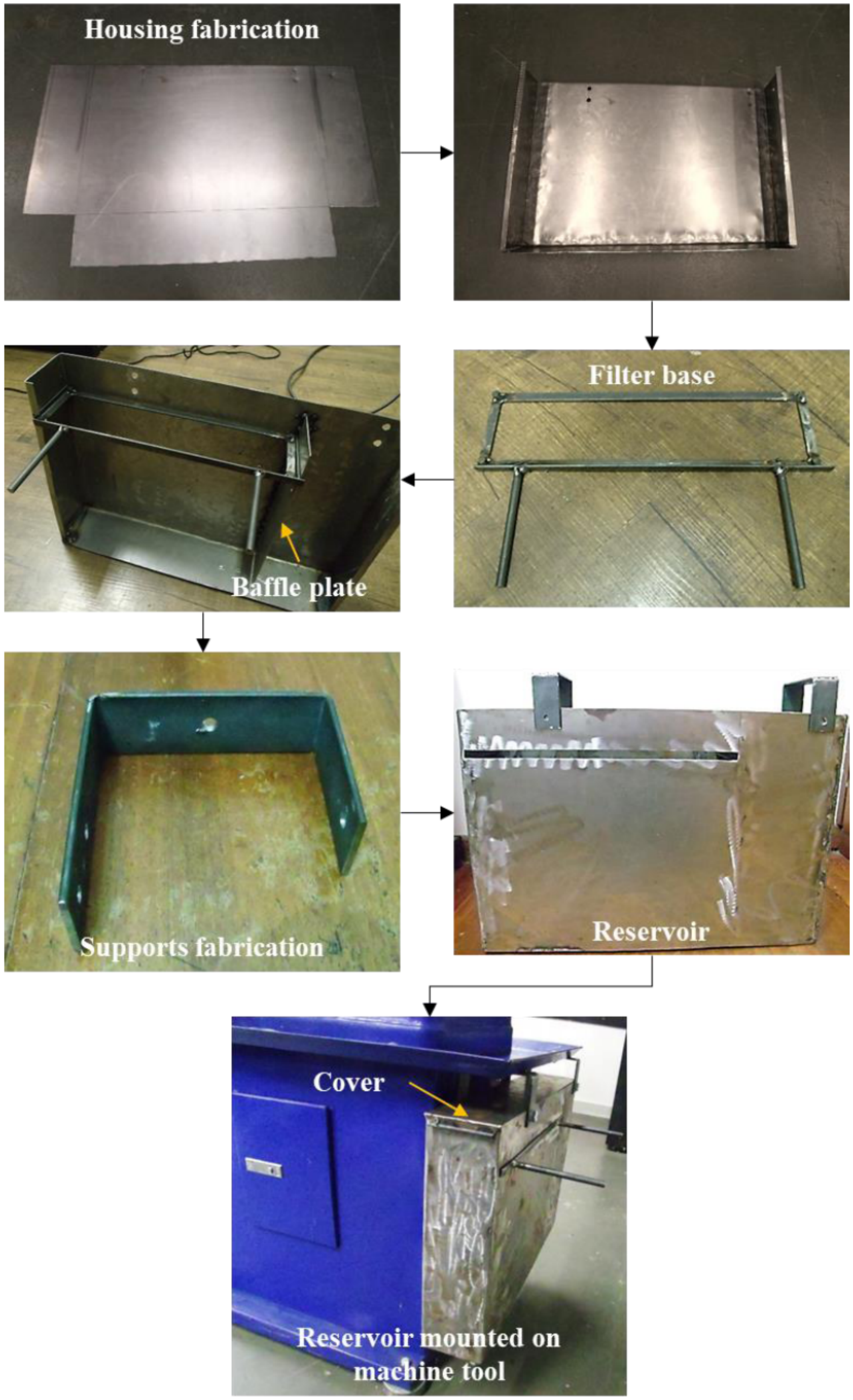

Figure 9: Illustration of the main steps taken during the manufacture of components of the cutting fluid application system.

left) in horizontal movement. Then, the discharge hose, with a nominal diameter of 12.7 mm, was mounted between the reservoir and the articulated tube for projecting the cutting fluid.

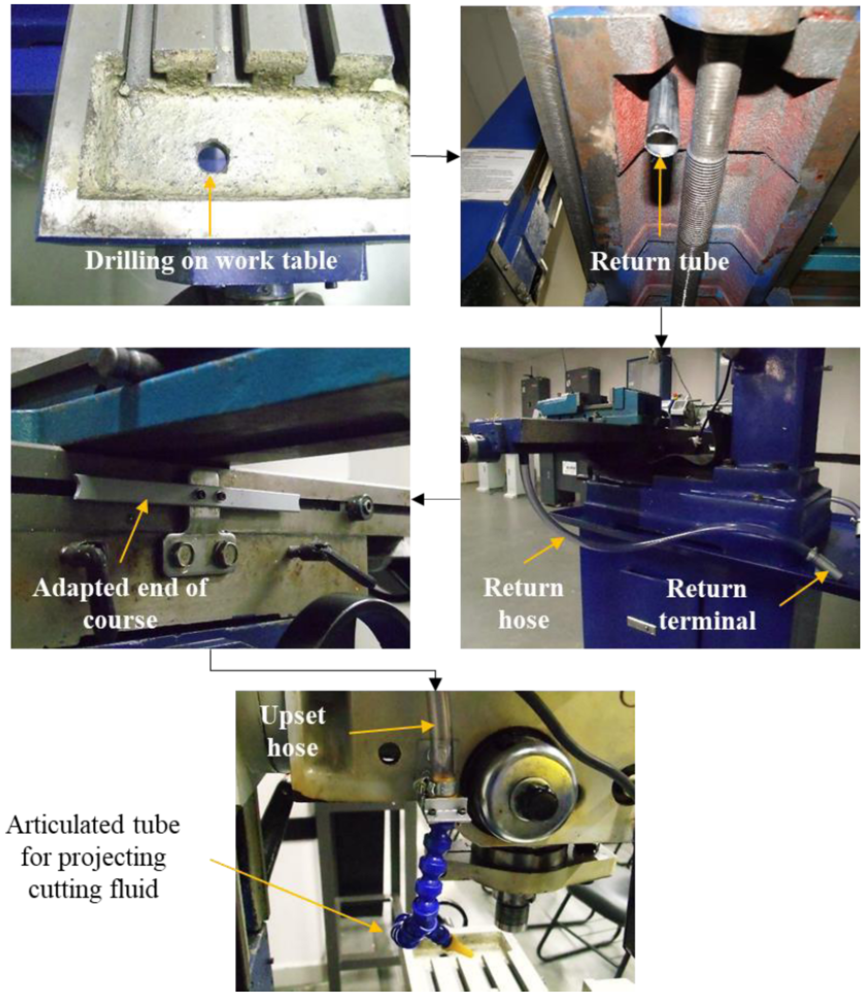

Figure 10: Illustration of the adaptation stages carried out on the machine tool to adapt the cutting fluid application system.

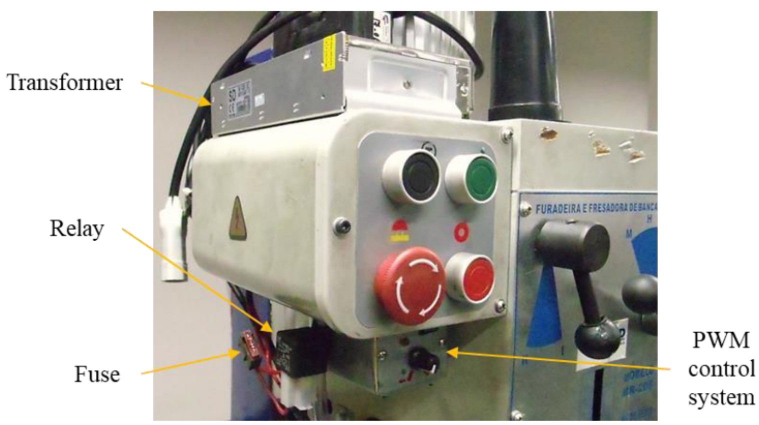

Figure 11: Illustration of the adaptation of the electrical drive and cutting fluid flow control system.

In Figure **11**, the fastening of the components of the electrical drive system and flow control of the cutting fluid is presented. The transformer and the pump control system were fixed on the electrical panel of the machine tool to facilitate its access to the operator. In the control system formed by the PWM [18, 19], the auxiliary relay activation switch was inserted in a small metallic box. A 10 amp fuse has been added for system protection.

Once the system assembly was completed, all metallic and structural components were removed from

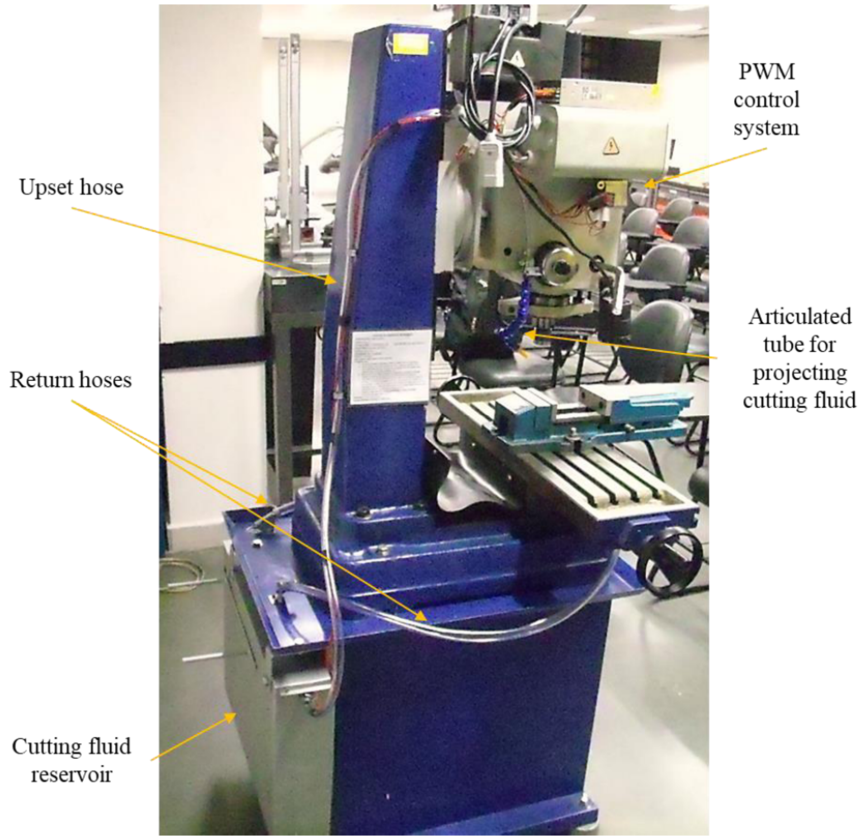

Figure 12: Illustration of the completely adapted machine tool, with all the components of the cutting fluid application system.

the machine tool to be coated with Hammerite synthetic enamel, which was applied with spraying equipment and diluted in turpentine in the proportion recommended by the manufacturer (75% enamel and 15% of turpentine). After applying the coating, drying was carried out in an open environment with sunlight for one week. Then the components were reassembled, concluding the manufacture and assembly of the cutting fluid application system on the machine tool (Figure **12**).

3.3. Validation of the Cutting Fluid Application System

First, a visual inspection was performed only with the system running with a 100% cutting fluid flow set. At this stage, no leakage was detected. The absence of drainage channels on the machine tool's work table meant that the cutting fluid filled the entire surface of the machine before returning to the reservoir. With the aid of a brush, the operator's intervention was necessary to direct the remaining cutting fluid to the return holes after using the system. Furthermore, after the system was turned off, a quantity of cutting fluid remained trapped in the return hoses.

In the machining operation, as shown in Figure **13**, directing the cutting fluid to the cutting region, it was necessary to reduce the pump flow to approximately 80 L/h, adjusting the PWM controller, to avoid waste and soften the spreading in the work environment. Naturally, some chips were thrown off the table, hitting the machine tool plate, which required the operator, after use, to guide these chips to the plate return holes. The chips thrown at the table were rarely conducted with the fluid to the return holes, requiring operator intervention after machining. In this test, the system filter did not perform as expected in terms of chip retention, as they arrived with difficulty and in small quantities in the reservoir. Furthermore, it was observed that, after a dry machining process, the machine tool operator spontaneously moved all the chips on the worktable to the return holes. Consequently, the chips were trapped in the return hoses or completely obstructed the return holes. In some of these occurrences, it was necessary to disconnect the return hoses to carry out the unblocking process. Cintia and Francisco [5] mention that cutting fluid and chip stagnation can contribute to the proliferation of microorganisms, which requires

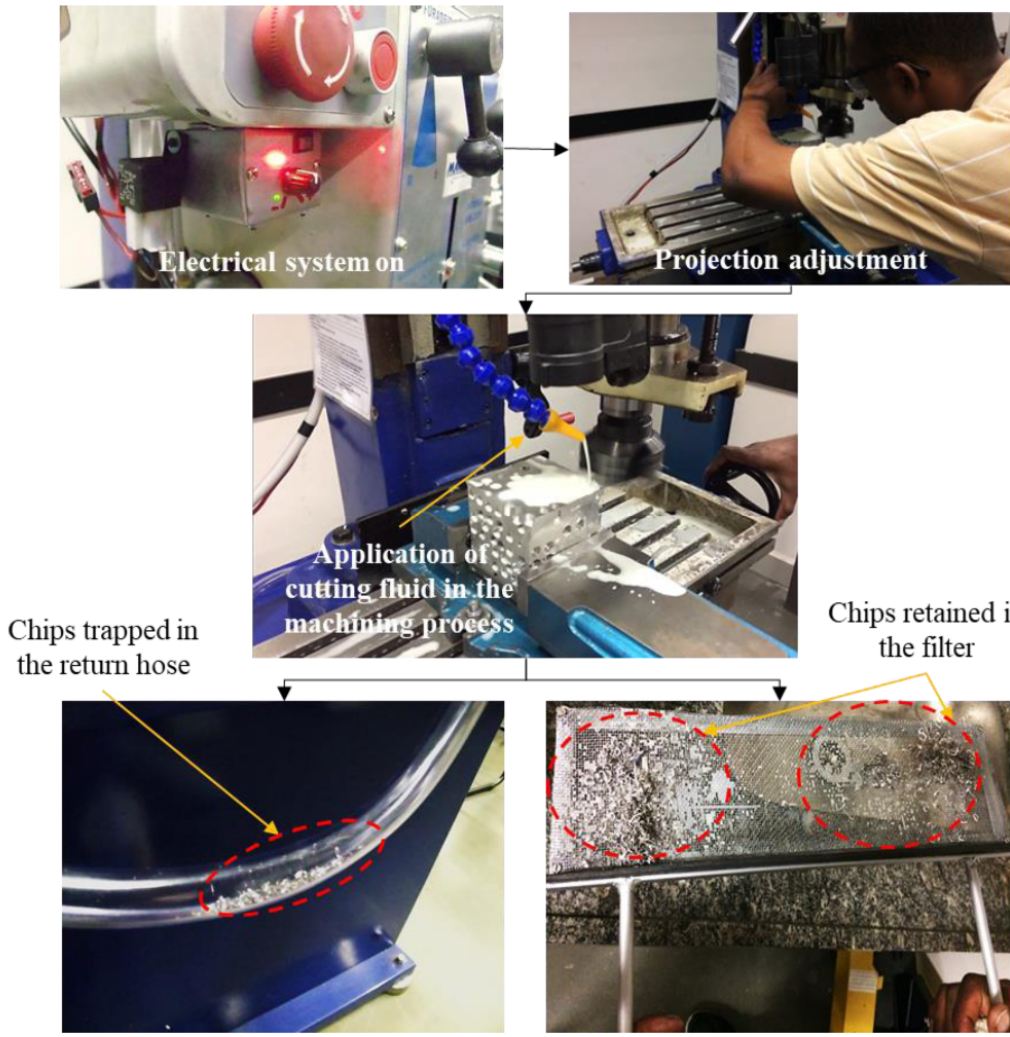

Figure 13: Record of the steps observed during the use and validation tests of the cutting fluid application system.

standard cleaning procedures after use in the machine tool.

The tests showed the positive and negative aspects of the system implemented in the machine tool. As for the positives: the location of the reservoir and the discharge and return lines did not negatively affect the handling of the machine tool, there were no leaks, the storage of cutting fluid in the reservoir provided good isolation from the external environment, the electrical system presented easy handling and allowed fluid flow adjustment to avoid waste, and the use of the articulated tube provided cutting fluid projection adjustments. The downsides were the deficiencies noted in the system's return paths: first, the diameter of the return holes machined into the worktable hindered the filter's functionality. Second, the curves present in the hoses provided the retention of chips and cutting fluid, which, consequently, would have greater contact with the external environment and could cause an unpleasant odor over time.

4. CONCLUSION

This study presented the design of a cutting fluid application system proposed for a machine tool present in an academic environment. Information in the literature determined relevant points to structure the project, such as the cutting fluid selection, its application method, and the basic assumptions for the reservoir construction. It was essential to use three-dimensional modeling to visualize the assembly and construction of components, making the methodological execution satisfactory.

On the other hand, it was not easy to discuss the results based on the literature, as the proposal of the present study presented a distinction from the proposals addressed in other scientific articles. Thus, it can be mentioned that the theoretical basis of the discussion was multidisciplinary, covering different studies that contained punctual and relevant information to achieve the proposed objective. Therefore, this study can contribute to the reduction of this "gap" of scientific information that is necessary for the development of other similar studies.

As for the proposed objective, on a qualitative scale from 0 to 100%, the cutting fluid application system reached 70% of the expected result. Constant yet adjustable fluid delivery has been achieved to avoid too much fluid wastage. The 30% not reached is due to deficiencies in the return lines that required unexpected intervention, at first, by the operator. For example, better results could be obtained in the possibility of increasing the diameter of the return holes machined on the machine tool table. In addition, the use of the system over time is necessary to show how efficient the filter will be as a function of the pump's useful life.

5. LIST OF ABBREVIATIONS AND SYMBOLS

CNC	Computer Numerical Control
MIG	Metal Inert Gas
MQL	Minimum Quantity Lubrication
PWM	Pulse Width Modulation
P_1	Static fluid pressure at reference point 1 (Pa)
P_2	Static fluid pressure at reference point 2 (Pa)
V_1	Flow speed at reference point 1 (m/s)
V_2	Flow speed at reference point 2 (m/s)
z_1	Elevation of reference point 1 (m)
z_2	Elevation of reference point 2 (m)
α_1	Kinetic energy correction factor in reference point 1 (dimensionless)
α_2	Kinetic energy correction factor in reference point 2 (dimensionless)
ρ	Fluid density (kg/m^3)
g	Acceleration of local gravity (Earth, g = 9.807 m/s^2)
ν	Fluid kinematic viscosity (m^2/s)
μ	Dynamic viscosity of fluid [kg/(m.s)]
R_e	Reynolds number (dimensionless)
$f_{friction}$	Darcy friction factor (dimensional)
$\dot{V}$	Volumetric flow (m^3/s)
$V_{average}$	Average flow rate (m/s)
D	Internal pipe diameter (m)
ε	Roughness of pipe material (m)
L	Straight pipe length (m)
L_T	Total pipe length, including all fittings (m)
K_L	Lower pipe loss coefficient (fittings) (dimensionless)
ΔP	Pressure variation (Pa)
h_L	Total pipe load loss (m)

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CONFLICT OF INTEREST

The authors have no financial or proprietary interests in any material discussed in this article.

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REFERENCES

[1] França PHP, Barbosa LMQ, Fernandes GHN, da Silva LRR, Machado ÁR, Martins PS, et al. Thermal analysis of a proposed internally cooled machining tool system. International Journal of Advanced Manufacturing Technology 2022. https://doi.org/10.1007/s00170-022-10602-8

[2] de Lima Menezes S, Otto Cunha Lima R. Estudo sobre a reciclagem de fluidos de corte aplicados no processo de torneamento por um filtro confeccionado com materiais de fácil acesso 2021:13-24. https://doi.org/10.21708/issn27635325.v3n1.a9962.2021

[3] Wu X, Li C, Zhou Z, Nie X, Chen Y, Zhang Y, et al. Circulating purification;. Additive;. Base oil;. Minimum quantity lubrication. The International Journal of Advanced Manufacturing Technology 2021; 117: 2565-600. https://doi.org/10.1007/s00170-021-07854-1

[4] Singh J, Gill SS, Dogra M, Singh R. A review on cutting fluids used in machining processes. Engineering Research Express 2021; 3. https://doi.org/10.1088/2631-8695/abeca0

[5] Caroline Callegaro Francisco Ignácio Giocondo Cesar C, Caroline Callegaro C, Ignácio Giocondo CESAR F. Manuseio DE Fluidos de Cortes: da Utilização ao Descarte 1. n.d.

[6] Holmes PM. Factors affecting the selection of cutting fluids. Industrial Lubrication and Tribology 1971; 23: 47-55. https://doi.org/10.1108/eb052964

[7] Debnath S, Reddy MM, Yi QS. Environmental friendly cutting fluids and cooling techniques in machining: a review. J Clean Prod 2014; 83: 33-47. https://doi.org/10.1016/j.jclepro.2014.07.071

[8] El Baradie MA. Materials Processing Technology Cutting Fluids: Part II. Recycling and Clean Machining. vol. 56. 1996. https://doi.org/10.1016/0924-0136(95)01893-X

[9] Sen B, Mia M, Krolczyk GM, Mandal UK, Mondal SP. Eco-friendly cutting fluids in minimum quantity lubrication assisted machining: a review on the perception of sustainable manufacturing. International Journal of Precision Engineering and Manufacturing-Green Technology 2019: 1-32. https://doi.org/10.1007/s40684-019-00158-6

[10] Ravi S, Gurusamy P, Mohanavel V. A review and assessment of effect of cutting fluids. Mater Today Proc, vol. 37, Elsevier Ltd; 2020; p. 220-2. https://doi.org/10.1016/j.matpr.2020.05.054

[11] Waste Reduction Center I. Cutting Fluid Management: Small Machining Operations. 2003.

[12] Okokpujie IP, Sinebe JE, Amiebenomo SO, Tartibu LK, Adeoye AOM. Development of a high-pressure delivery lubrication system for sustainable machining operations. Mater Today Proc 2022; 62: 4533-8. https://doi.org/10.1016/j.matpr.2022.05.007

[13] Hu K, Phonepasith M. Development of automatic control system for cutting fluid filtration. IOP Conf Ser Earth Environ Sci, vol. 692, IOP Publishing Ltd; 2021. https://doi.org/10.1088/1755-1315/692/3/032088

[14] Shen ZY, Chen CY, Lee MT. Recovery of cutting fluids and silicon carbide from slurry waste. J Hazard Mater 2019; 362: 115-23. https://doi.org/10.1016/j.jhazmat.2018.09.014

[15] Karimi A. Session 5-1 Application of Excel in Solving Heat Exchanger Problems. 2008.

[16] Outram JG, Couperthwaite SJ, Martens W, Millar GJ. Application of non-linear regression analysis and statistical testing to equilibrium isotherms: Building an Excel template and interpretation. Sep Purif Technol 2021; 258. https://doi.org/10.1016/j.seppur.2020.118005

[17] Çengel YA, Cimbala JM. Mecânica DOS Fluidos. 1st ed. São Paulo: McGraw Hill-Artmed; 2007.

[18] Rahman RA, Suwandi A, Nurtanto M. Experimental investigation on the effect of thermophysical properties of a heat transfer fluid on pumping performance for a convective heat transfer system. Journal of Thermal Engineering 2021; 7: 1628-39. https://doi.org/10.18186/thermal.1025910

[19] Dong J, Shi J, Liu C, Yu T. Research of Pneumatic Polishing Force Control System Based on High Speed On/off with PWM Controlling. Robot Comput Integr Manuf 2021; 70. https://doi.org/10.1016/j.rcim.2021.102133

[20] Němec P, Stodola P. Optimization of the multi-facility location problem using widely available office software. Algorithms 2021; 14. https://doi.org/10.3390/a14040106

[21] Suwannahong K, Wongcharee S, Kreetachart T, Sirilamduan C, Rioyo J, Wongphat A. Evaluation of the microsoft excel solver spreadsheet-based program for nonlinear expressions of adsorption isotherm models onto magnetic nanosorbent. Applied Sciences (Switzerland) 2021; 11. https://doi.org/10.3390/app11167432

[22] Dario Dantas O, Medrado da Silva E, Gustavo Barioni L, Antônio Assfalk de Oliveira M, Enoch Furquim Werneck Lima J. Comparação Dos Métodos GRG2 (Solver Do Excel) E Downhill Simplex Para a Parametrização DA Função Beta. n.d.

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