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## LOW-COST SYRINGE PUMP DESIGN MODIFICATION FOR MINIMUM QUANTITY OF LUBRICATION SYSTEM APPLICATION

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**Abstract.** This work presents the implementation viability of a modified open-source syringe pump project in a cooling and lubrication MQL system. The focus of this research was to get a system with increased precision and flow measurement capabilities at lower costs than commercial ones. A calibration method was used to measure the accuracy of the built system. The injection system reached resolution of 0.0646  $\mu\text{L}$  per microstep of the stepper motor and price below 20% of similar products. These results are important allowing advancement in MQL researches and making this technology more accessible to small producers.

**Keywords:** MQL, Arduino, open-source, syringe pump, calibration.

### 1. INTRODUCTION

Machining processes are largely used for production of parts and equipment, at diverse production scales. Important points in these processes are lubricating and cooling fluids that are responsible to reduce friction between part and tool, also removing the heat generated in the process.

Lower temperatures increase the tool life and reduce machining time, therefore increase productivity. However, fluid deliver systems are responsible for about 17% of the total machining process costs (Alves, 2005), thereat it is an important point to reduce the cost, being the Minimum Quantity of Lubrication (MQL) or fluid (MQF) a new alternative to conventional flooding methods.

MQL consists in a flow of minimum quantity of atomized oil mixed with compressed air and located in the cutting region (Kondo et al., 2015). Its application in automotive industry presented less environmental impacts, better working environments for workers' health, lower water consumption, lower emission of greenhouse gases and decreased energy consumption resulting in reduction of total costs (Tai et al., 2014).

Kondo et al. (2015) reported their difficult in measuring and controlling a precise oil flow in their studies using commercial equipment. A solution for this problem is based in an open-source syringe pump project (Wijnen et al., 2014). The proposal of this work is to construct a low-cost device adapted to MQL system that allows precise metering and controlling of the oil flow, thus enabling advanced researches in machining lubrication and making such technology more accessible to small producers. It is also presented the calibration method to guarantee flow precision.

### 2. EXPERIMENTAL PROCEDURE

#### 2.1 Syringe Pump

The syringe pump was made by additive manufacturing in ABS polymer in a 3D printer model UP! Mini. Some modifications in original models were made to adequate the project to local market components and to adapt scrap parts from obsolete machines. The device is presented in Fig.1.

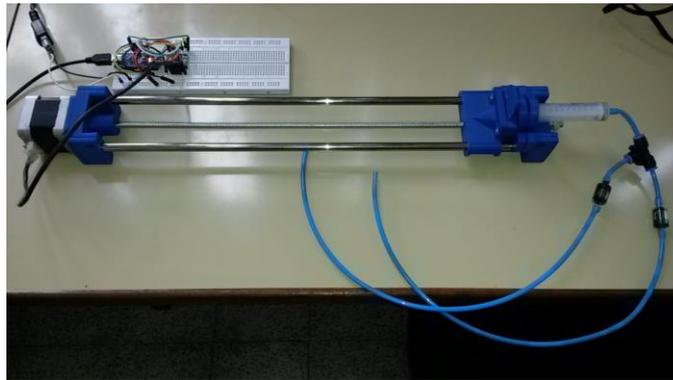


Figure 1. 3D printed syringe pump.

The system was built with a NEMA 17 bipolar stepper motor, controlled by a prototyping platform model Arduino Nano. The Arduino used a stepper motor driver integrated circuit model A4988 with microstepping feature, in which the microstep was 1/16 of the full step. It was used the AccelStepper Arduino Library (McCauley, 2017) in the programming of the microcontroller.

## 2.2 Calibration

Initially, to prepare the system for calibration, it was made two measures with random number of microsteps to estimate the dislocated volume of each microstep. This value was used to convert the levels of the experimental factors.

A small positive displacement of the piston was made before every measure to compensate the screw backlash.

The experiment was done following a factorial design of experiments. The injections speed and dislocated volume are two important factors for a MQL system, therefore they were used as main factors of the factorial  $2^2$  design. The response analyzed was the resolution in dislocated volume/microstep.

The calibration was made by measuring the dislocated mass of distilled water ( $m_{H_2O}$ ) after a desired motor displacement in microsteps at a constant speed, based in the initial preparation. The dislocated mass was converted in volume using a table of distilled water density ( $\rho_{H_2O}$ ) at the temperature in the moment of the measurement (Perry, 1963) divided by the respective number of microsteps ( $N$ ), as given by Eq. (1).

$$R = \frac{m_{H_2O}}{\rho_{H_2O} \cdot N} \quad (1)$$

Where  $R$  is the value of resolution in mL/microstep,  $m_{H_2O}$  is the dislocated mass of distilled water in g and  $\rho_{H_2O}$  the distilled water density in the temperature of the measure in g/mL.

The conversion is necessary because the parameters used in the microcontroller program are injection speed, in microsteps/s, and dislocated volume, in microsteps while in the experiment design the unit of injection speed and dislocated volume are, respectively, mL/s and mL.

Each experiment was made three times to enable an experimental error calculation, then the results was used to calculate effects of the factors and the interaction between them.

The Table 1 shows the equivalent values for the factors levels. The injection speed levels were defined according to usual literature values (Kondo et al. 2015).

Table 1. Factors equivalent values.

Factor	Low level (-)	High level (+)
Injection speed (mL/s)	$5.55 \times 10^{-3}$ (20 mL/h)	$8.33 \times 10^{-2}$ (300 mL/h)
Dislocated volume (mL)	0.5	5.0

## 3. RESULTS AND DISCUSSION

Starting from the two initial random measures, it was obtained a resolution of  $6.44 \times 10^{-5}$  mL/microstep. The Table 2 shows the factors equivalent values in microsteps. These values were implemented in the programming of the microcontroller.

Table 2. Factors equivalent values in microsteps.

Factor	Low level (-)	High level (+)
Injection speed (microsteps/s)	87	1294
Dislocated volume (microsteps)	7763	77629

The Table 3 shows the experimental levels and the mean value of volume per microsteps already converted from the mass by the distilled water density in the temperature of each measurement.

Table 3. Experimental matrix for the factorial experiment.

Experiment	Factors		Mean value of Resolution (mL/microstep)	Variance
	Injection speed	Dislocated volume		
1	-	-	$6.36 \times 10^{-05}$	$6.57 \times 10^{-14}$
2	+	-	$6.46 \times 10^{-05}$	$6.64 \times 10^{-14}$
3	-	+	$6.44 \times 10^{-05}$	$1.78 \times 10^{-15}$
4	+	+	$6.47 \times 10^{-05}$	$4.54 \times 10^{-15}$

These experimental results were used to perform a statistical analysis to calculate the effects of the main factors and the effects of the interaction between them. The Tab. 4 shows the statistical analysis parameters and results.

Table 4. Statistical analysis parameters and results

Parameter	Value
Number of experiments	12
Degrees of freedom	8
Significance test	Student's <i>t</i>
Confidence level	95%
Student's <i>t</i> value	2.306
Result	Value
Main effects	$E_{speed} = 7.01 \times 10^{-7}$ (t-value = 3,766) $E_{volume} = 4.08 \times 10^{-7}$ (t-value = 2,192)
Interaction effect	$E_{interaction} = -3.24 \times 10^{-7}$ (t-value = 1,743)
Significant effect	$E_{speed}$

As shown in the Tab. 4 only injection speed effect is significant. It was probably caused by water evaporation since it was made in a non-isolated system and the lower speed increased the exposition of the water to the environment. The main effects for the response Resolution are shown in Fig. 2.

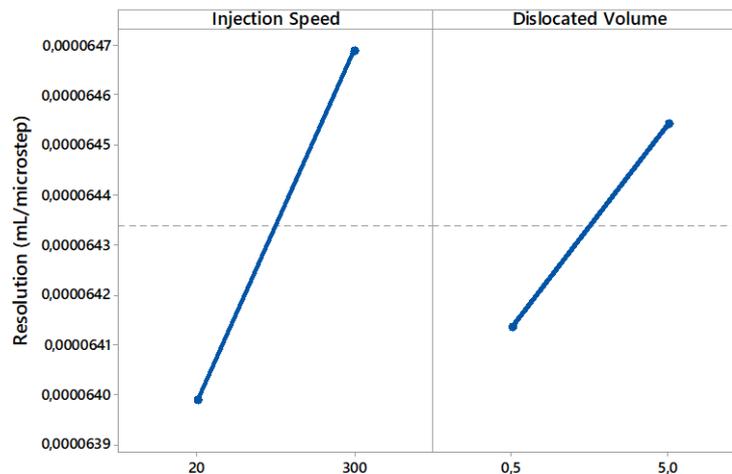


Figure 2. Main effects for Resolution.

In the Fig. 2 it is noticeable the difference in the variation that each factor causes in the resolution, reinforcing the significance of the injection speed effect in the system even with this deviation being around 1.7%.

Because of this evaporation effect, the chosen values to calibrate the syringe were those obtained with the faster injection speed to minimize it, therefore the calibrated value of volume per microstep is  $6.46 \times 10^{-5}$  mL.

#### 4. CONCLUSIONS

From the analysis of the syringe pump system, it is possible to conclude that although its accuracy is in the order of tenths of  $\mu\text{L}$ , it is still applicable in MQL systems due to high flows of fluid used when compared to such precision, thus, the objective of the work has been achieved.

It is still necessary to develop other 3D printable parts of the device to complete the low-cost system, such as the coupling and atomizer that make the union of the air and oil hoses and atomization of the oil and these remain as suggestions of future work.

#### 5. ACKNOWLEDGEMENTS

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#### 7. RESPONSIBILITY NOTICE

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