MODIFICATION, INTEGRATION AND TESTING OF MULTI POWDER HOPPER WITH CO-AXIAL NOZZLE FOR LASER CLADDING

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Dr. Najam ul Qadir

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We hereby recommend that the dissertation prepared under our supervision by: **Ahsan Ali (322324)**, Titled: "Modification, Integration and Testing of Multi Powder Hopper with Co-Axial Nozzle for Laser Cladding" be accepted in partial fulfillment of the requirements for the award of Master's degree

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ABSTRACT

1. The applications of Laser Metal Deposition (LMD) in favor of mankind are vast and the benefits of LMD as compared to conventional cladding processes necessities high level of research in low equipment cost especially for under develop countries like Pakistan. LMD process not only gives lower heat affect zone (HAZ) problems but also less dilution and porosity issues compared to other type of cladding processes. Due to Functionally Graded Materials (FGMs), this additive manufacturing technique is getting popular in biomedical, defense, automotive and aerospace industries. Multiple metal powders are allowed to pass via a nozzle and incoming powder-metal is simultaneously melted through a powerful laser beam thus forming a melt pool. After solidification a metal clad of different grade is formed and process is repeated for other layers. Thus, by changing the metal powder proportion the clad properties can be changed resulting into better functional properties of the part.
2. The main equipment of LMD consists of powder feeding mechanism, optical Laser system and a nozzle. The powder feeding mechanism is important for FGM and consist of multiple solutions, one of them is control of feeder discs with stepper motor controls, which is successfully considered in this research. The aim of this research is to re-design a multi powder hopper machine and a co-axial nozzle. Moreover, integration of in-house design co-axial clad nozzle with powder feeding system is a challenging task. This is followed by testing of complete system to quantify the efficiency of both nozzle and multi-powder hopper machine with respect to powder mass flow rate and concentration of powder stream at the nozzle exit. As the whole setup is an initial prototype and limits the use of laser at this stage therefore other parameters affecting the Laser cladding process cannot be validated. However, LMD is a vast technique in additive manufacturing and is expected to grow under advance research activities.

Keywords: Laser Meta Deposition, Powder Flow Rate, Co-axial Nozzle, Powder Focus, Stepper Motor Control, GUI

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CHAPTER 1: INTRODUCTION

Background

1. The 21st century is a century of rapid social changes in our society. The increase concern of climate change has awaken the world to invest more on innovative ideas which can save our planet. One of these innovation involve use of additive manufacturing (AM). The use of this technology can not only save the natural resources but can also reduce the degradation effect on our eco system. Researchers have highlighted the importance of 3D printed buildings related to reduction in environmental pollution and human injuries[1]. Ford and Despeisse shows 60% material saving and 30% time saving with the use of the AM technology [2].

2. Similarly, the pattern of consumption is also changing. The consumers who have knowledge about impact of carbon foot prints are becoming conscious of their products. Recycling, repairing, renovating and regenerating are becoming top trends between the top heads of manufacturing industries[3]. One of the AM which can help the industry to restore parts is Laser Cladding or is Laser Metal Deposition (LMD), which is the focus of this research. In fact, this technology has a mass potential for repair of damaged aircraft components as well [4].

3. Laser Metal Deposition (LMD) is an emerging technology around the world due to its vast capabilities. This type of Additive Manufacturing (AM) is known for its less dilution with the substrate metal, formation of thin layers and less HAZ as compared to conventional cladding processes like welding, spraying, plasma arc, chemical vapor deposition (CVD), mechanical plating and electrochemical cladding techniques. The drawback of this technology is the high cost which may not be affordable for under develop countries. Therefore, a low cost solution with similar efficiency is important. The solution can be developed by segregating the main modules of the LMD and finding cost-effective solutions to these particular modules. The Laser Cladding consists of following main modules for the process:

a. Powder Feeder
b. Laser Nozzle
c. Laser head
d. Part Platform

4. The powder Feeder consist of multiple hoppers for containing various metal powder for cladding and known as Functionally Graded Materials (FGMs). The research on development of low cost Powder Feeder and Laser Nozzle is carried out at NUST. However, the control of powder feeder is still an issue at low RPM and integration and testing of powder feeder with Laser nozzle is also to be done. Although the testing process consist the risk to human health due use of laser and metal particles but that can be mitigated through careful usage of equipment and alternatives to powder metal. Moreover, proper use of safety gear will also reduce the risk to human health.

Scope of Research

5. The scope of this research is to test multi-powder hopper machine with co-axial nozzle, while monitoring the powder mass flow rate and focus, for efficient working of the indigenously manufactured system.

Aim and Objectives

6. *The aim of this research is to* ***redesign co-axial nozzle and MPH*** *machine for flow of powder stream from MPH to the nozzle outlet. The objectives include determining the effect of change in disc RPM on powder mass flow rate using indigenously developed Laser cladding system.*

7. The research objectives are mentioned below:

a. Modifying the control of Multi Powder Hopper (MPH) discs at low RPMs.
b. Development of a graphical user interface for optimized control of MPH.
c. Integration of MPH with co-axial nozzle for cladding of FGMs.
d. Testing of powder mass flow rate and powder stream from MPH via co-axial nozzle.

Outline of Thesis Report

8. This thesis report of comprises total of 5 chapters as appended below:

a. Chapter 1: Introduction

b. Chapter 2: Literature Review

c. Chapter 3: Methodology

d. Chapter 4: Experimentation and Results

e. Chapter 5: Conclusion and Recommendations

CHAPTER 2: LITERATURE REVIEW

This chapter will provide the necessary theory required as a foundation for this research. An introduction of additive manufacturing will be the first area of this literature review, followed by introduction of specific additive manufacturing process to this project i.e Laser Metal deposition. The remaining sections will include the hardware control systems. The solutions to graphical user interface are presented at the last.

2.1 Additive Manufacturing

Additive manufacturing (AM) is an overall term for many fabrication technologies. In which a 3D data model is fabricated in layer by layer approach and process is repeated several times. 3D printing, Rapid Prototyping, Additive Layer Manufacturing and Freeform Fabrication are also used for this manufacturing technique. 3D printing is more common in commercial terms and additive manufacturing is used in industries [5]. The F42 Technical Committee of American society for testing and materials (ASTM) on Additive Manufacturing defines it as “process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies” [6].The AM technology is no more a prototyping technology and sales of AM technologies has increased. Despite of the COVID-19, 7.5% increase was observed in growth of AM technology in year 2020 as shown in figure 1 [7].

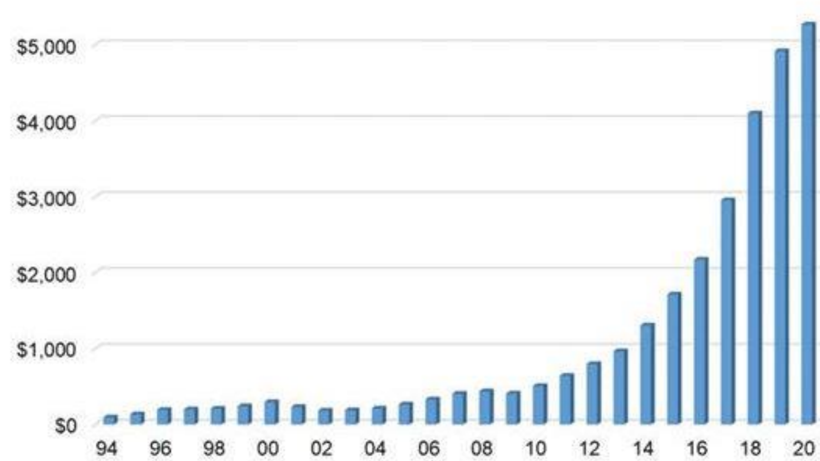


Figure 1 Production of AM parts (in millions of dollars). Source: Wohler’s Report 2021

2.2 Classification of AM

There are various types of additive manufacturing technologies and can be classified as per type of process, material (Solid, Liquid, Powder), feed mechanism and energy used in the process. However, the focus will be on powder based AM techniques and primarily on Laser metal deposition (LMD) which is also known as Direct energy deposition figure 2. The boxes highlighted in orange are of interest for this research. The main difference between Direct energy deposition and powder bed fusion is the method of introducing powder.

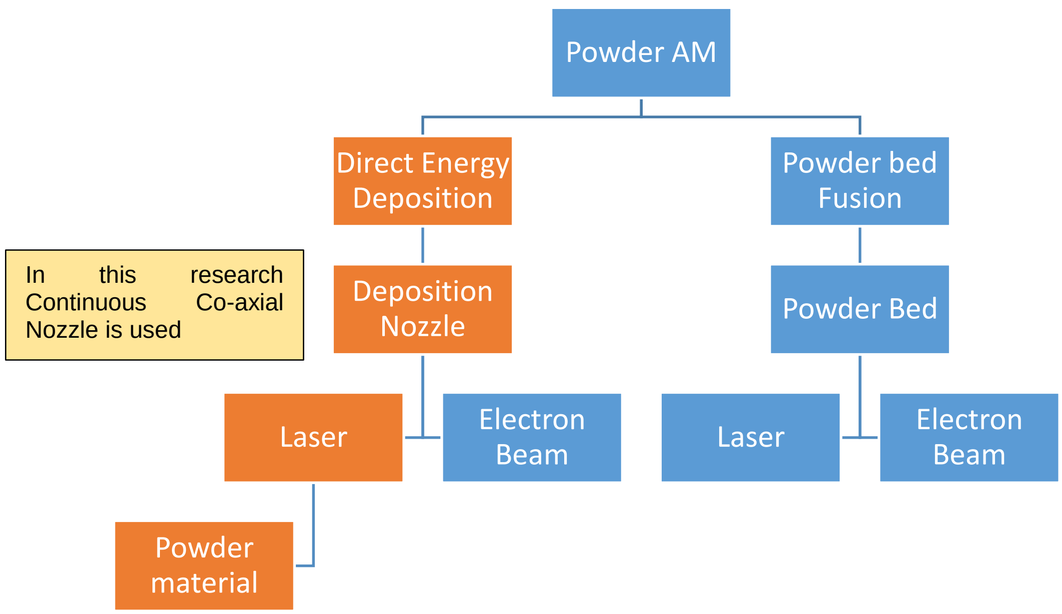


Figure 2 Classification of Powder AM (modified from ASTM 2015)

A pre-placed powder is used in powder bed fusion and direct energy deposition uses simultaneous flow of powder with laser beam melting the powder thus creating a metallurgical bond after rapid solidification [8].

2.3 Advantages of AM

a. There are numerous advantages of AM especially in aerospace industry. According to Ford & Despeisse, 60% material saving 30% time saving can be accomplished with use of LMD [2].

b. The customization of design changes or utilizing of similar equipment for different products can be achieved with AM technologies [9].

c. AM allows manufacturing of intricate parts and save cost. As per GE aviation, 75% of fuel nozzle cost can be cut off by using AM technologies [10].

d. The below table shows the use of AM technology in medical and aerospace industries modified from EPMA 2015 [5]:

<table>
<tr><td rowspan="2">Repair of worn lips on a labyrinth seal</td><td>Industry</td><td>Aerospace</td><td rowspan="2"></td></tr>
<tr><td>Additive process</td><td>Laser Metal Deposition</td></tr>
<tr><td rowspan="2">Removable Partial Denture Framework</td><td>Industry</td><td>Dental (Medical)</td><td rowspan="2"></td></tr>
<tr><td>Additive process</td><td>Laser Beam Melting</td></tr>
</table>

Table 1: Benefits of AM

2.4 Direct Energy Deposition

Direct energy deposition or Laser Metal deposition (LMD) uses a powder stream as a feed material and a nozzle. This stream is fed through a carrier gas (generally Argon) from the nozzle outlet to the surface. Simultaneous melting of powder occurs via a laser beam and a thin layer is formed [11], see figure 3.

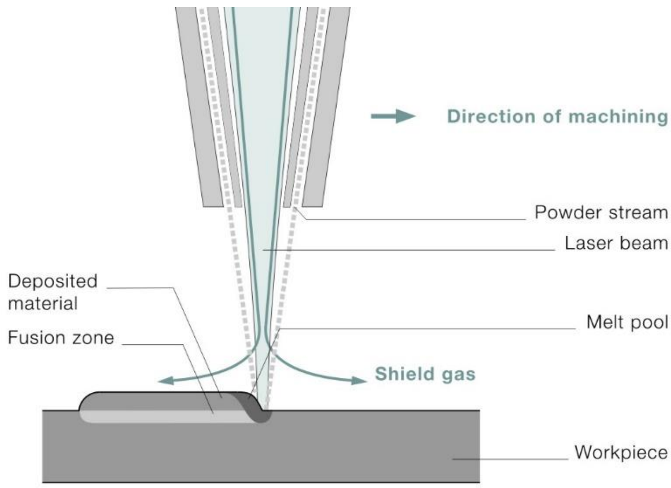


Figure 3 Illustration of LMD with coaxial nozzle

The system of nozzle, laser and gas tubes is called deposition head. The deposition head and work piece are controlled relative to each other with automatic system[8].

2.5 Powder Feeding System

The powder is fed via a rotating disc comprises of annular slot for carrying the powder from a container called hopper. Hopper itself comprised of a stirring mechanism for continuous flow of powder into the rotating disc. The flow of powder is illustrated in block diagram (figure 4).

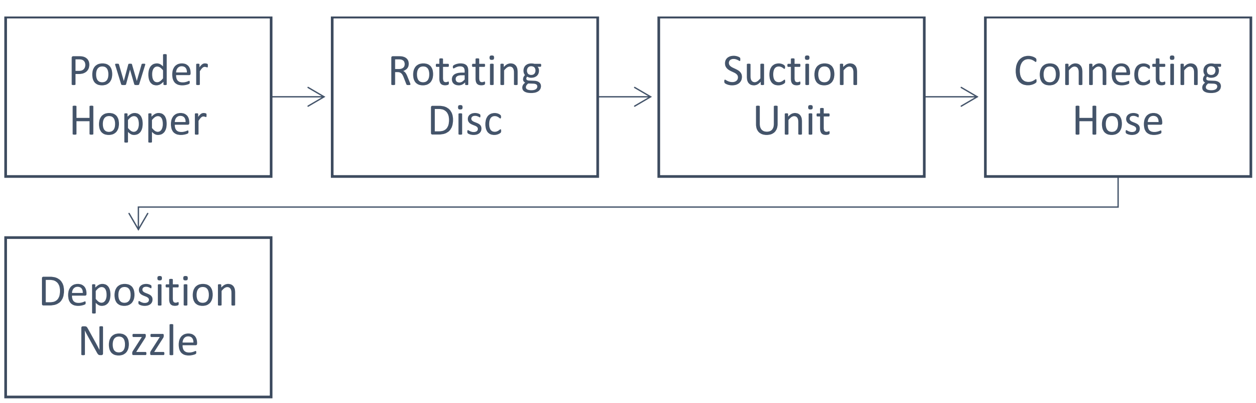


Figure 4 Flow of Powder

The rotating disc also consist of a suction mechanism on the other end. Once powder is reached near the suction unit, it is then transported to the depositing nozzle via a hose. The suction unit operates with a carrier gas and this gas mainly responsible for transportation of powder from disc to the nozzle. Consequently the powder mass flow rate is controlled by the disc RPM [12], figure 5 [13].

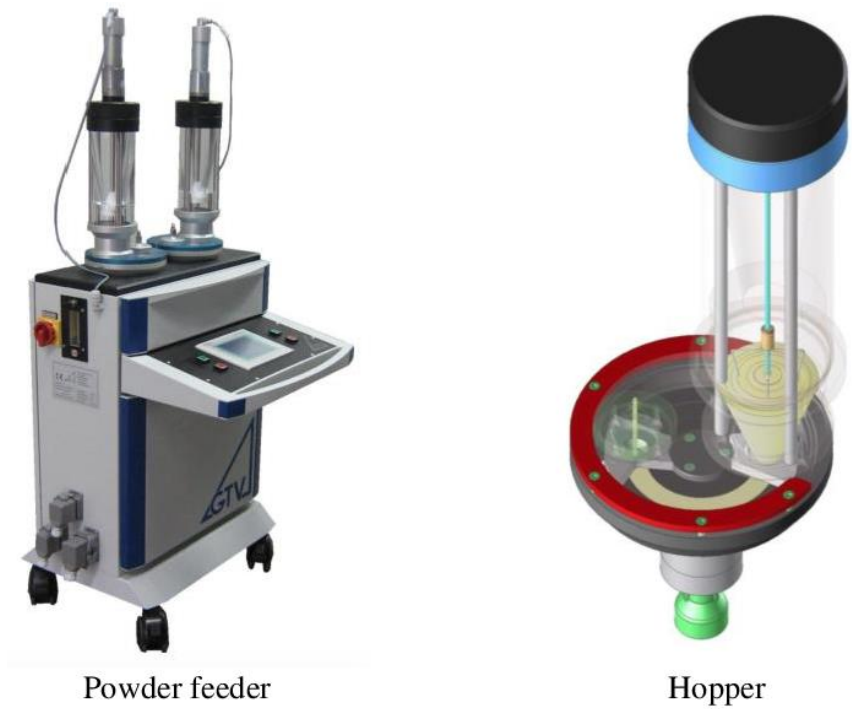


Figure 5 GTV Powder Feeders

2.6 Deposition Nozzle

A deposition nozzle is mounted on a multi axis control system and is used to deposit melted powder onto a substrate surface. In general, co-axial or radially aligned nozzle is used, figure 6 referred.

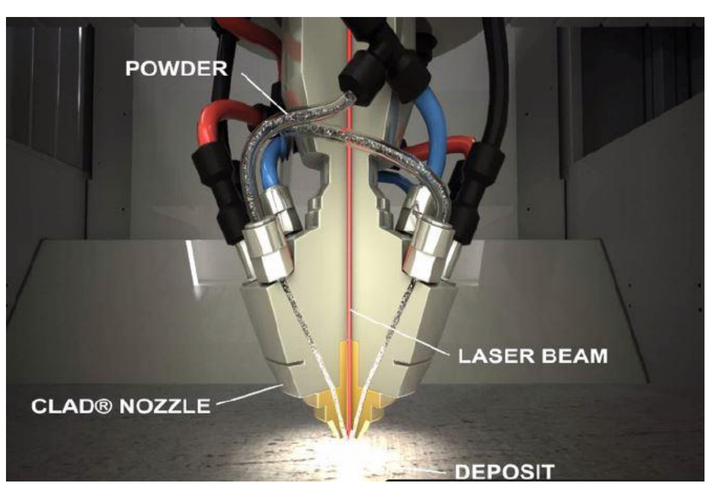


Figure 6 Direct Energy Deposition CLAD (Courtesy of BeAM)

The co-axial nozzle is further divided into continuous annular powder nozzle[14] and discrete multi jet nozzle [15] as shown in figure 7.

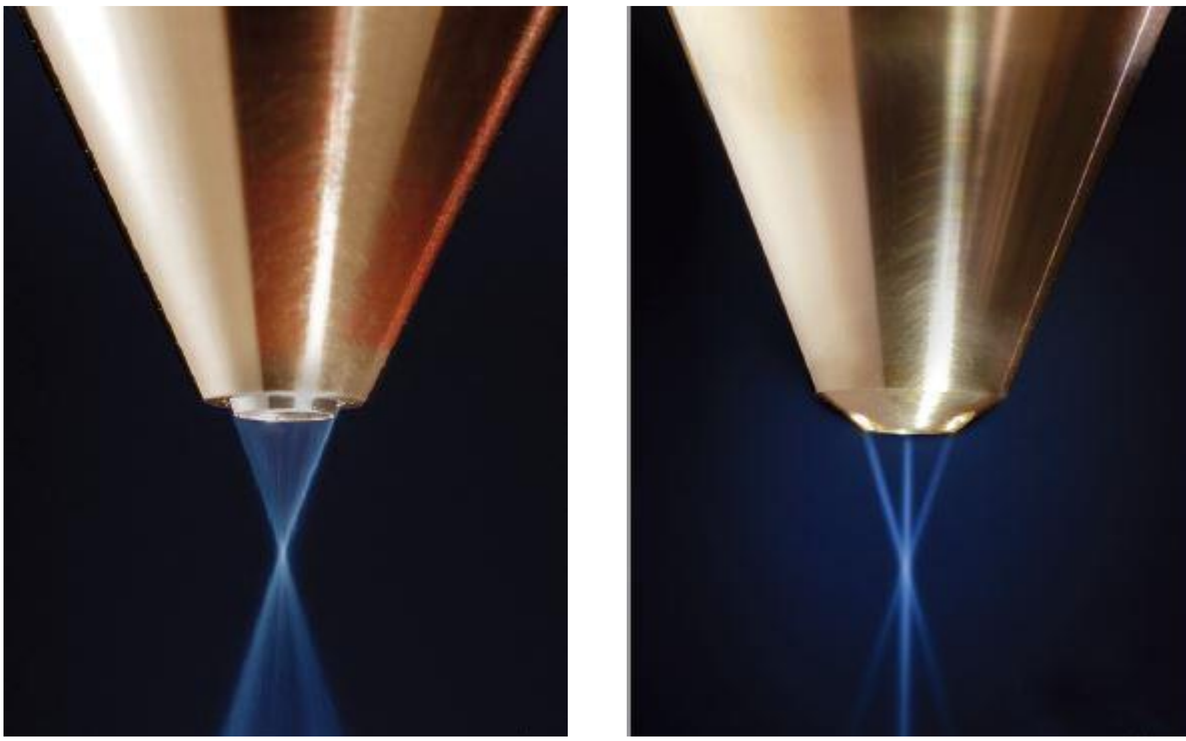


Figure 7 Co Axial Powder Nozzle (Left) Three Jet Powder Nozzle (Right)

2.7 Major Parameters for efficient LMD

The structure of final clad is dependent on various parameters but mainly it is dependent on following operating parameters [16]:

a. Laser Power
b. Laser Scan Speed
c. Powder mass flow rate

The melt pool formed in DED process is studied by researchers and it was revealed that width of melt pool increases with increase in powder mass flow rate, decreasing scan speed and high laser power. However, melt pool width remain constant when Laser power is set below settings [16, 17]. Laser power and scan speed will be different for different composition of materials. With Low Laser power, scan speed needs to be slow for depositing more material and with more laser power the process can be fast for depositing same amount of material but problem of dilution may occur [18, 19]. The powder mass flow rate increases the clad height but the laser power has limited effect on it [16].

2.8 Characteristics of Powder Material

Researchers have chosen following powder characteristics for Laser metal deposition [20]:

a. Spherical Particles

b. Less Internal Porosity

c. Narrow size distribution

d. Less surface pores

e. High purity and good flowability

2.9 Control of Hardware

The hardware (Rotating Discs) can be controlled using motors and microcontroller and one of the inexpensive and open source microcontroller is Arduino [21, 22]. The 8-bit Arduino Mega 2560 microcontroller is focused in this research due more number of pins as shown in figure 8.

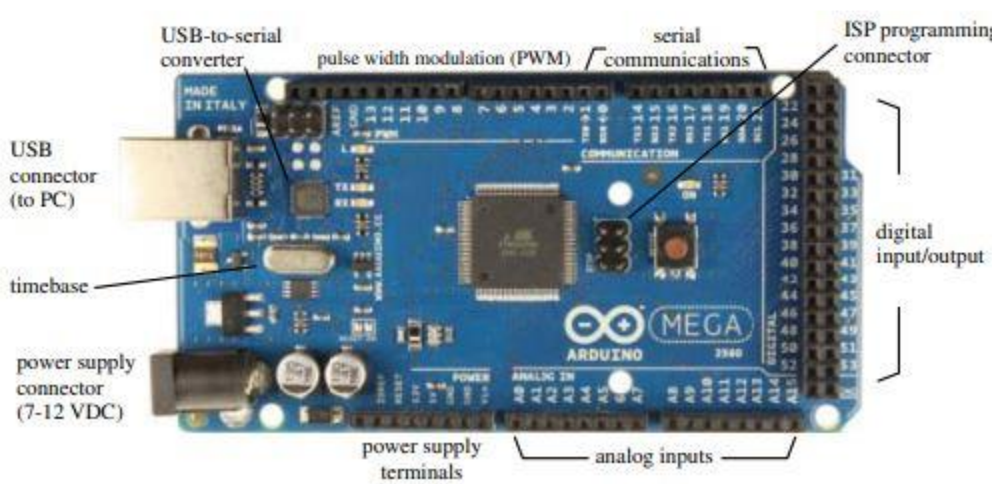


Figure 8 Arduino Mega2560 Layout

2.10 Graphical User Interface (GUI)

Arduino Serial Monitor within the open source software of Arduino software i.e IDE Integrated development environment can be used to enter input to the Arduino microcontroller but there are other options to interface Arduino microcontroller with other computational software like MATLAB and LabVIEW. However, the Arduino IDE is based on processing software. Processing offers multiple languages like Java, Python mode, R etc and is a unified system which integrates programming language, development environment and visual concepts [23]. Due to the simplicity and easy interface with Arduino Processing 3.0 was used for visual controls.

2.11 Stepper Motors

According to British Standard Specification a stepper motor can be defined as:

"*It is a brushless DC motor whose rotor rotates in a discrete angular increment upon energization of stator windings. The rotor has no electrical windings, but has magnetized poles*" [24].

An internal view of stepper motor is shown in figure 9 [25]. The phase (A- ,B- ,A+, B+) coils are connected with stepper motor driver. Due to current limit on microcontrollers a motor driver is generally used. The microcontroller sends the command to the motor driver which in turns run the motor [26].

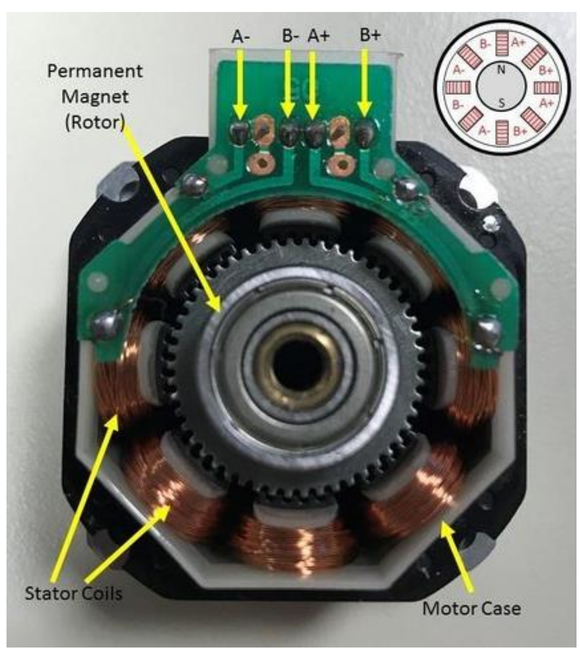


Figure 9 Stepper Motor Internal view

CHAPTER 3: METHODOLOGY

In this chapter reader is directed towards the methodology adopted during the phase of this research. The research was divided into three phases after analyzing already completed work by Ali and Umair [27, 28]. The layout of the adopted methodology is shown in below figure.

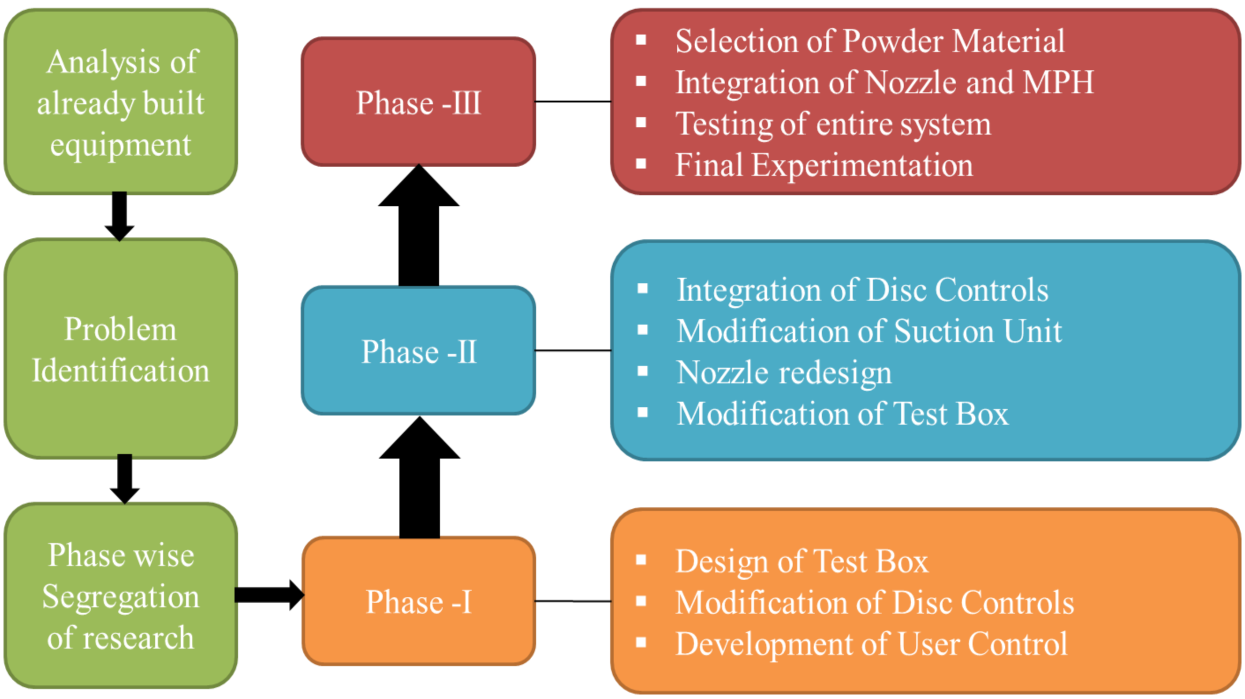


Figure 10 Methodology Layout

3.1 Problem Identification

1. The multi powder hoppers built previously were fitted with DC motor control. Consequently, frequent problems of motor stall were faced at low disc RPM, as shown in figure 11. Moreover, a grinding noise was observed during rotation of the discs.

2. The previously developed LabVIEW interface with Arduino was unable to run all 3 motors simultaneously and tests were performed on each hopper by switching ON/OFF each motor at a time.

3. The suction of the indigenously developed pumps, as shown in figure 12, was not sufficient for the flow of powder from hopper to the nozzle.

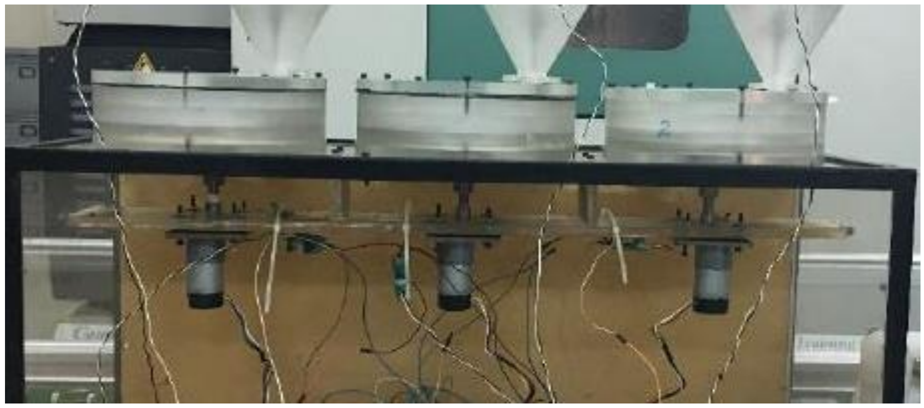


Figure 11 Previously incorporated DC Motors

Figure 12 Old Suction Pump

4. The pressure distribution mechanism from compressor to Multi-Powder Hopper (MPH) machine was limited to one hopper only.

5. The integration of MPH with Co-axial nozzle (figure 13), followed by testing needed to be carried out.

Figure 13 Co-Axial Nozzle

3.2 Phase-I Design of Test Box

In order to contain the powder flow within a container and to view the powder flowing from the nozzle during test, an acrylic box was design from a local vendor placed at Lahore. Transparent acrylic sheet of 4 mm were used for design of the box. The dimensional specification of box are in table 2 and CAD model is shown in figure 14:

Height of the Box	1.5 feet (18 inches)
Width of the Box	1 feet (12 inches)
Length of the Box	1 feet (12 inches)

Table 2 Test Box Dimensions

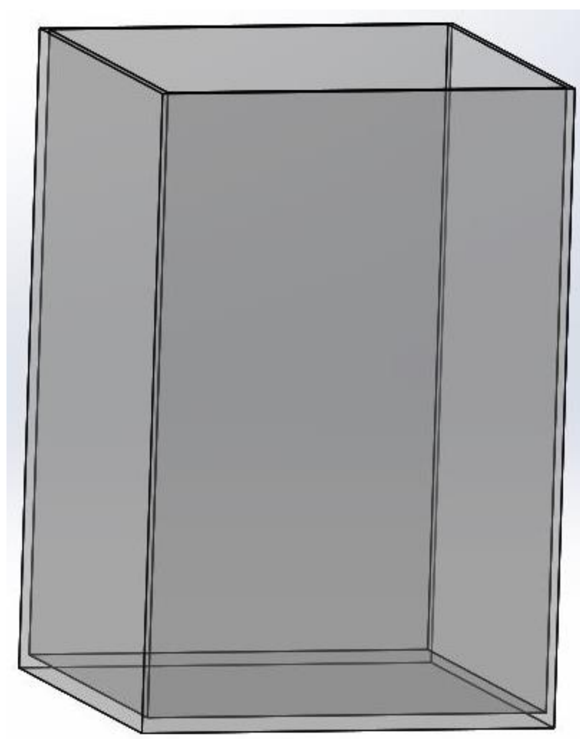


Figure 14 CAD Model of Test Box

3.3 Phase-I Modification of Disc Control

Stepper Motor and Driver

Option for modification of disc controls at low rpm were searched in local market and the solutions quoted were at exorbitant price. Therefore, it was decided to establish in-house solution of the task. Subsequently, a 4 wire bi polar stepper motor was selected instead of DC motor due to its ability to provide torque at low speed and high accuracy. Details of motors are appended in table 3.

Model	Nema 17
Price	650 PKR
Shaft Dia	5mm
Step Angle	1.8 degree
No. of steps for 360 degree rotation	200
Phase current	1.2 A
Holding Torque	40 N.m
Wire	4(Blue, Green, Black, Red)

Table 3 Specifications of Stepper Motor

The motor is not used alone directly with Arduino and a driver is included between motor and Arduino. There are multiple drivers available in market but not every driver is compatible with Nema 17 stepper motor. The driver used in this research is “EasyDriver” which is built in at 16 steps micro stepping mode which is a technique to reduce the size of a step angle. Subsequently, high accuracy and smoother motion can be achieved with micro stepping. The EasyDriver is by default at 1/8th step configuration [29]. This mean that step angle of Nema 17 when using with default configuration of EasyDriver will be 0.225 (1.8/8) degrees. This built-in micro step settings will generate heating of driver when running motors. Therefore, an extra heat sink was used for protection against overheating of EasyDriver as shown in figure 15.

Figure 15 EasyDriver with an Extra Heat Sink

Mounting of Stepper Motors

The old base plates of DC motors were modified as per new Nema 17 stepper motors and were fitted inside the MPH frame as shown in figure 16.

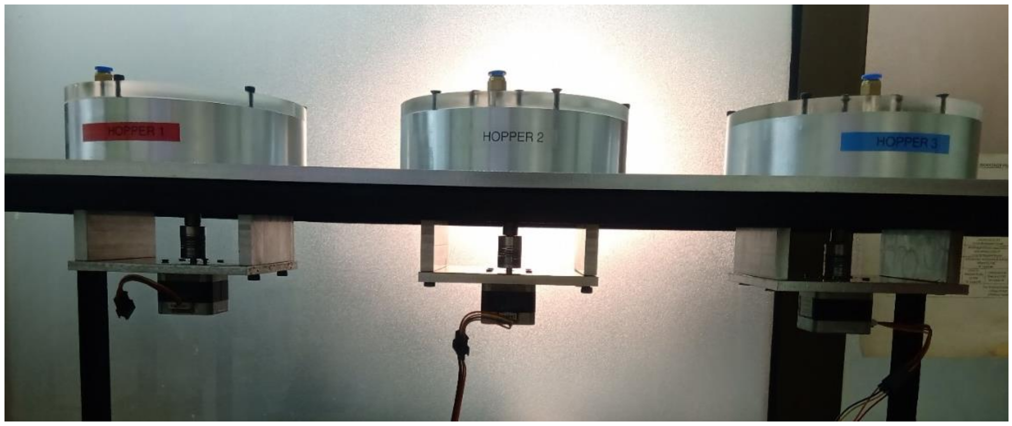


Figure 16 Stepper Motors Integrated with Discs

Circuit Diagram

The final circuit consisted of 3 stepper Motors, 1 Arduino Mega2560 (Master Circuit), 3 Drivers (Slave Circuits), 12V power Supply and a Laptop. The signal can be transmitted manually from Arduino Serial monitor or user interface of Processing 3.0, which will be delivered to the EasyDriver and consequently to the coils of stepper motor. Circuit layout is shown in figure 17. Complete circuit diagram is attached as appendix 'A'. Due to micro stepping, overheating of Driver I/Cs occurred As a protection measure, Aluminum Heat sinks were integrated with the I/Cs.

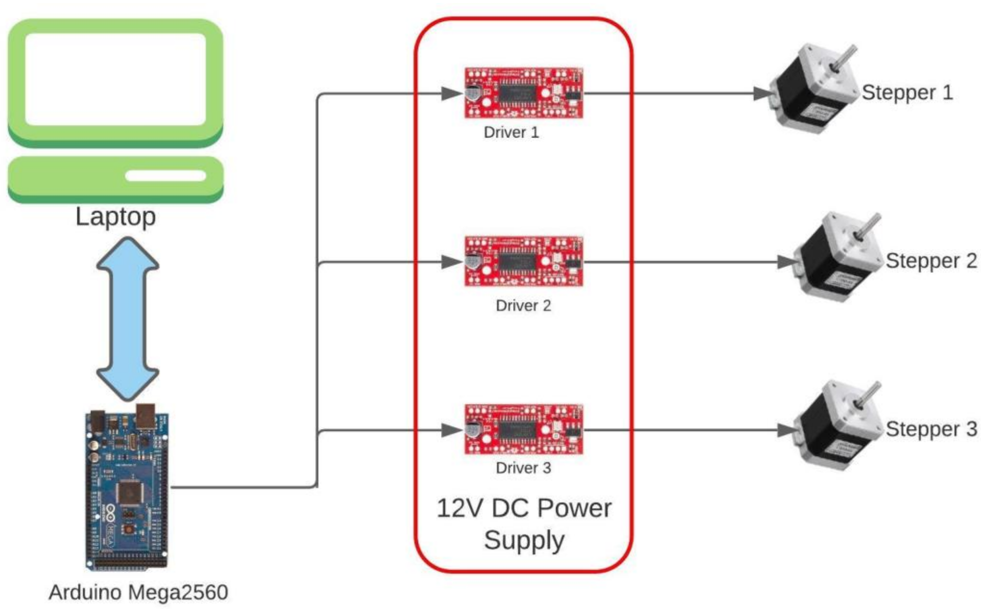


Figure 17 Layout of Circuit

Arduino Code

In order to simultaneously run all 3 stepper motors with independent speed on each stepper, AccelStepper library was used [30]. The flow chart of code is shown in figure 18 and complete code is attached as appendix “B”.

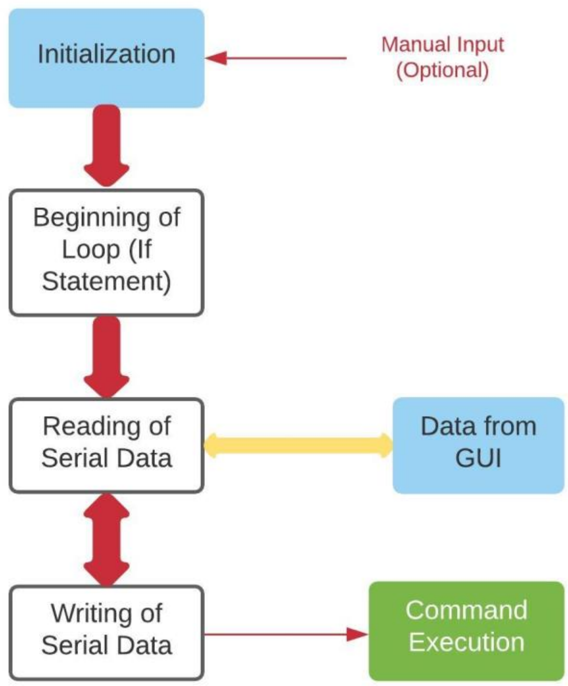


Figure 18 Code Flow Chart

Speed of Motor

In Arduino code the speed of stepper motor is set as steps per second (Pulse Rate i.e; frequency of pulses we send to STEP pin). Therefore, the required steps were calculated as follows:

1 full Revolution = 360 degrees

Step Angle (with EasyDriver) =1.8/8 =0.225 degree

Therefore, 1 full rev = 360/ 0.225 = 1600 steps/revolution

Equation A $$Pulse\ Rate = Steps\ per\ Revolution\ in\ 1\ full\ Rev * RPS$$

For 10 RPM = (1600 steps/rev *10 rev/60 sec) = 266.66 steps/second

Due to the fact that low speed is required for efficient Laser Cladding, therefore steps per second for 1 to 10 RPM were calculated using equation A and are attached as appendix "C".

3.4 Phase-I Development of User Control

The user control was developed using an open source software "Processing 3.0" which is compatible with Arduino IDE. In order to keep the interaction easy for the users, the button controls were chosen for 1 to 10 RPM. The ControlP5 library was used for writing codes of button control in Processing sketch book [31]. The display of GUI is shown in figure 19 and the detail code is attached in appendix "D".

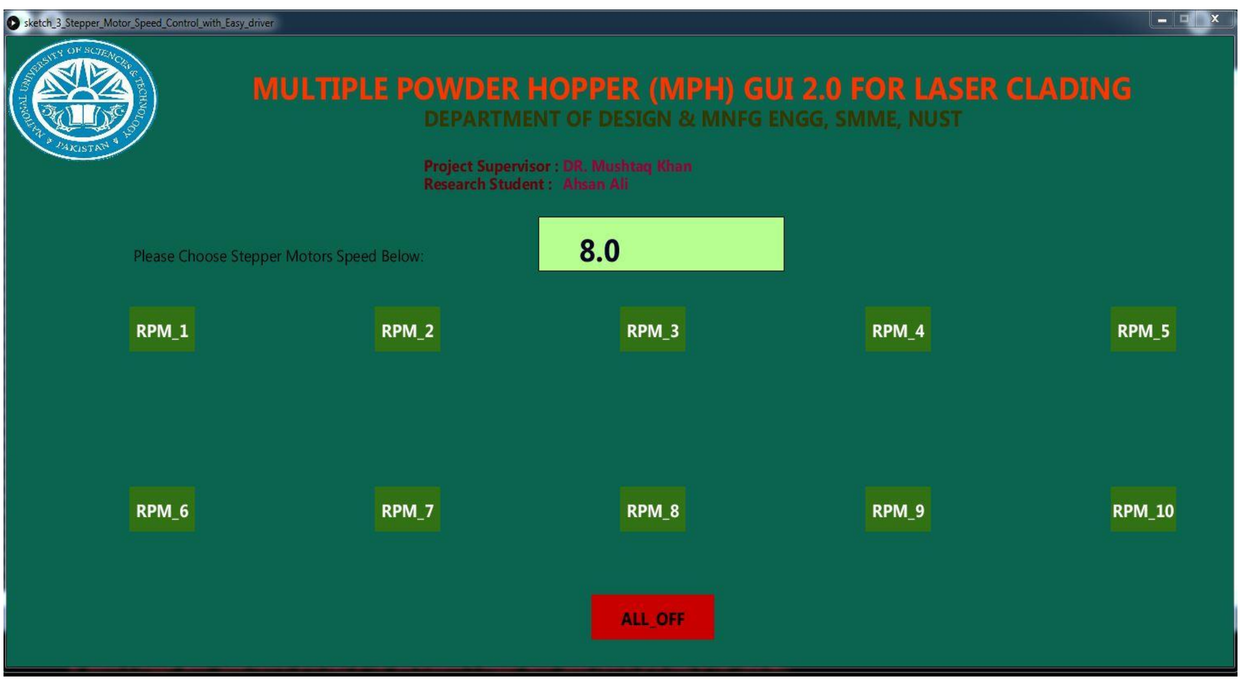


Figure 19 Screen Window of Processing 3.0

3.5 Phase-II Integration of Disc Control

An Aluminum base plate was designed for mounting new stepper motors. The shaft length of rotor disc was re-design for integration with new design of stepper motors and 5 x 8 mm flexible Aluminum shaft coupler was introduced for integration of motor and rotor disc. The shaft of Nema 17 stepper motors is inserted at one end of the coupling and shaft of rotating is coupled at the other end as shown in figure 20. Such that change in RPM of stepper motor changes the disc RPM. During initial testing, a grinding noise was observed from disc rotations. A 50 micron size grit paper was used to polish the Rotor discs (figure 21) and testing was carried out. Free and smooth motion was observed after that.

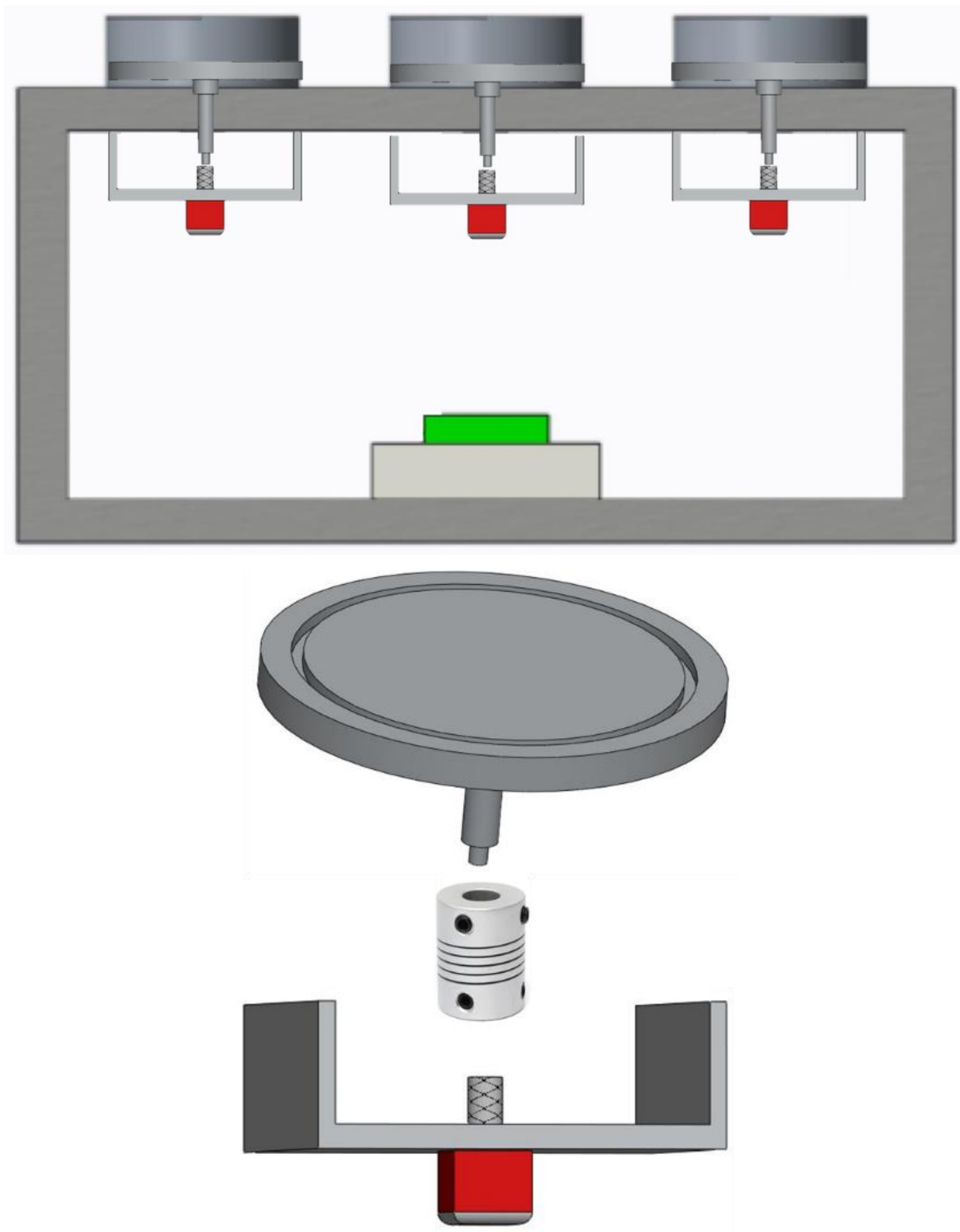


Figure 20 Coupling of Rotor Disc and Stepper Motor

Figure 21 Rotor Discs After Polish

3.6 Phase-II Modification of suction unit

Initially the design of a vacuum suction pump was studied. These pumps operate by a venturi effect where a pressure is dropped and velocity is increased [32]. This pressure difference is responsible for the suction of powder material. The previously built pump was evaluated based upon the literature review and was found insufficient for required suction. Due to economical availability of this pump from china, it was decided to procure 3 static vacuum conveyor pumps on immediate basis. The working pressure of pump was 0 to 0.7 MPa, pump shown in figure 22. The date sheet of the pump is attached as appendix “E”.

Figure 22 Vacuum Conveyor Pump

The pressure line was designed for continuous availability of dry compressed air, to all 3 pumps, at a fix rate, as shown in figure 23. The dry compressed air was ensured by adding a water filter at the compressor outlet. And a good quality Pressure distributor was used to avoid any unnecessary leakages in the system.

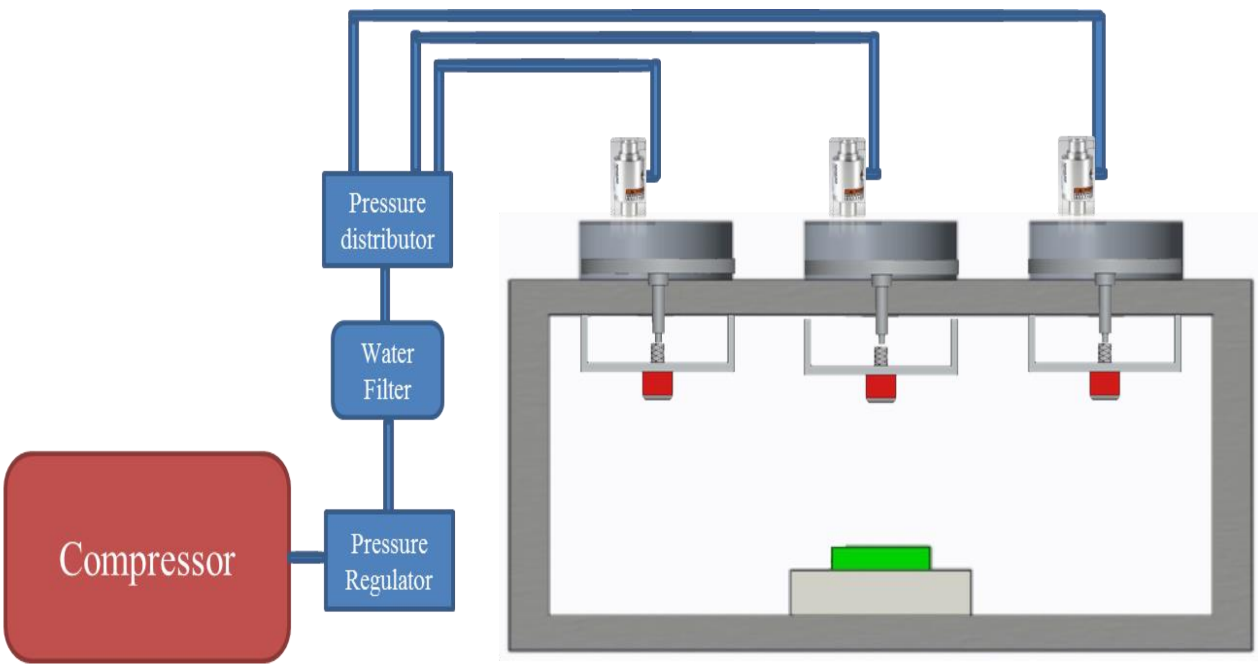


Figure 23 Design of a Pressure line

3.7 Phase-II Nozzle Re design

During initial testing the powder flow was observed insufficient when connected with 12mm Teflon pipe from suction unit to the Co-axial nozzle. The problem was analyzed and the previous pressure hose connectors were found problematic. The previous pressure hoses were of 6 mm and were converging thus dropping the pressure. Therefore, it was decided to re-design the Nozzle outer cowling for large pressure hose connectors. Moreover, the previous cowling was design for four hoppers. Therefore, a redesign was necessary for integration with 3 hoppers. In order to have symmetrical flow from the nozzle, the holes were separated 120 degrees apart as shown in figure 24.

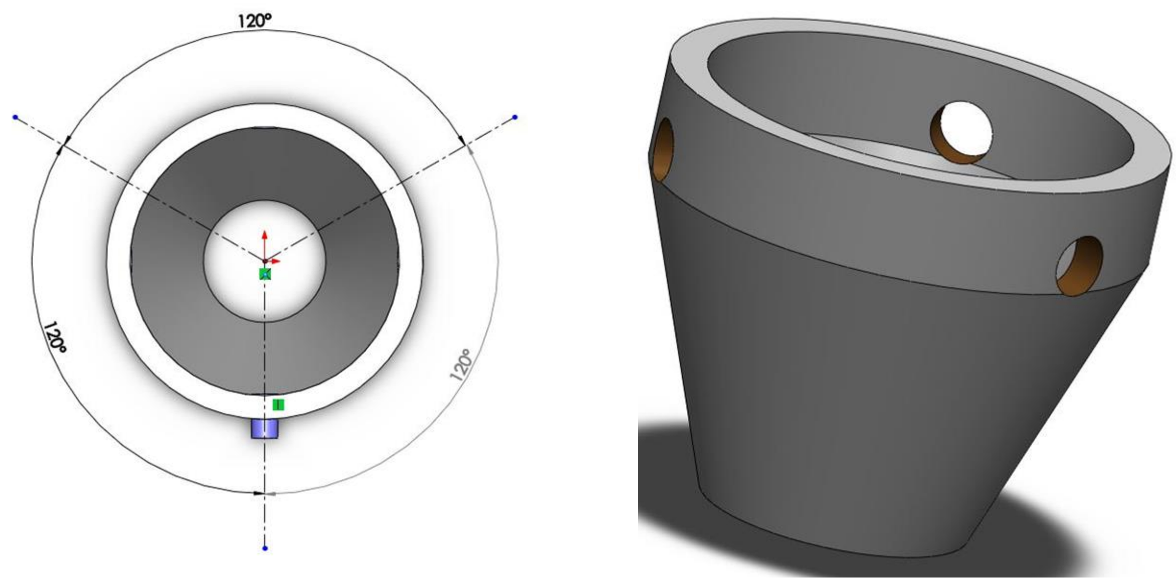


Figure 24 Re Design of Nozzle

3.8 Phase-II Modification of Test Box

In order to mount the nozzle inside the test box, 3 holes were drilled in the test box for insertion of flexible pipes which subsequently also acted as a supporting structure for holding the co-axial nozzle, as shown in figure 23. The test Box was also fitted with 6 filters from the outer pleat of surgical mask to contain the testing material inside the box and only to exhaust of air open, as shown in figure 25.

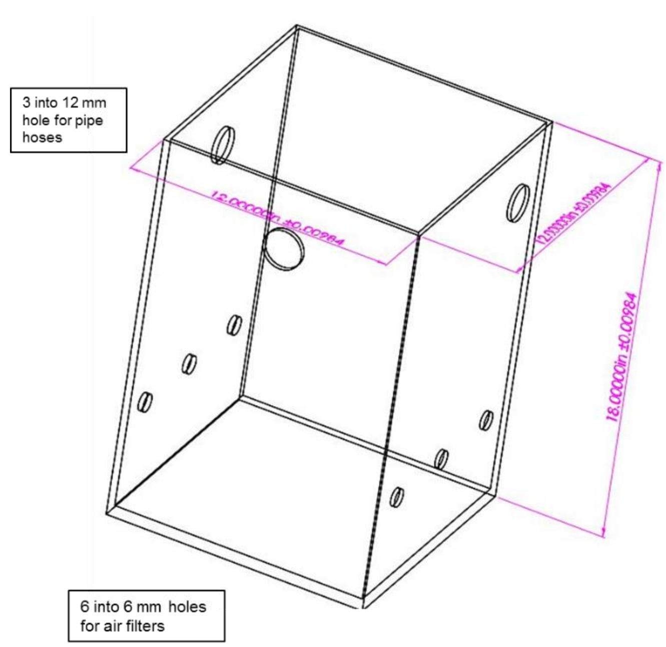


Figure 25 Modified Test Box

3.9 Phase-III Selection of Powder Material

As the equipment is in prototype stage, therefore directly using metal powder was considered hazardous. Moreover, spherical metallic powder is expensive and rarely available in local market (limited visits due COVID). Therefore, it was decided to choose an organic material with symmetrical shape. Poppy seeds were finally selected as shown in table 4.

Material	**Size**	**Reason for Rejection**	**Reason for Acceptance**
Silica sand (not organic)	70 micron	Non-organic, Irregular shape, High chance of particle lost	
Tea Particles	300 micron	Irregular shape, Porous, Poor flowability	
Poppy seeds	650 micron		Symmetrical shape, medium size and less chance of particle lost
Mustard seed	900 micron	Large size distribution	
Sago pearls	1000 micron	Large size distribution, Poor flow ability	

Table 4 Selection of Powder Material

3.10 Phase-III Integration of Nozzle and MPH

The Co-axial nozzle and MPH were integrated together with the help of flexible pipes. The suction unit was mounted on top of the suction inlet of static disc and outlet of suction unit was connected with nozzle inlet with help of flexible pipe. The pressure input to suction unit was provided via a compressor. In order, to ensure dry and clean air, a water filter was included at compressor exit. A pressure distributor was used to distribute pressure to 3 outlets which were eventually entering into the 3 suction units of the Multi-powder hoppers. The detail diagram is shown in figure 26.

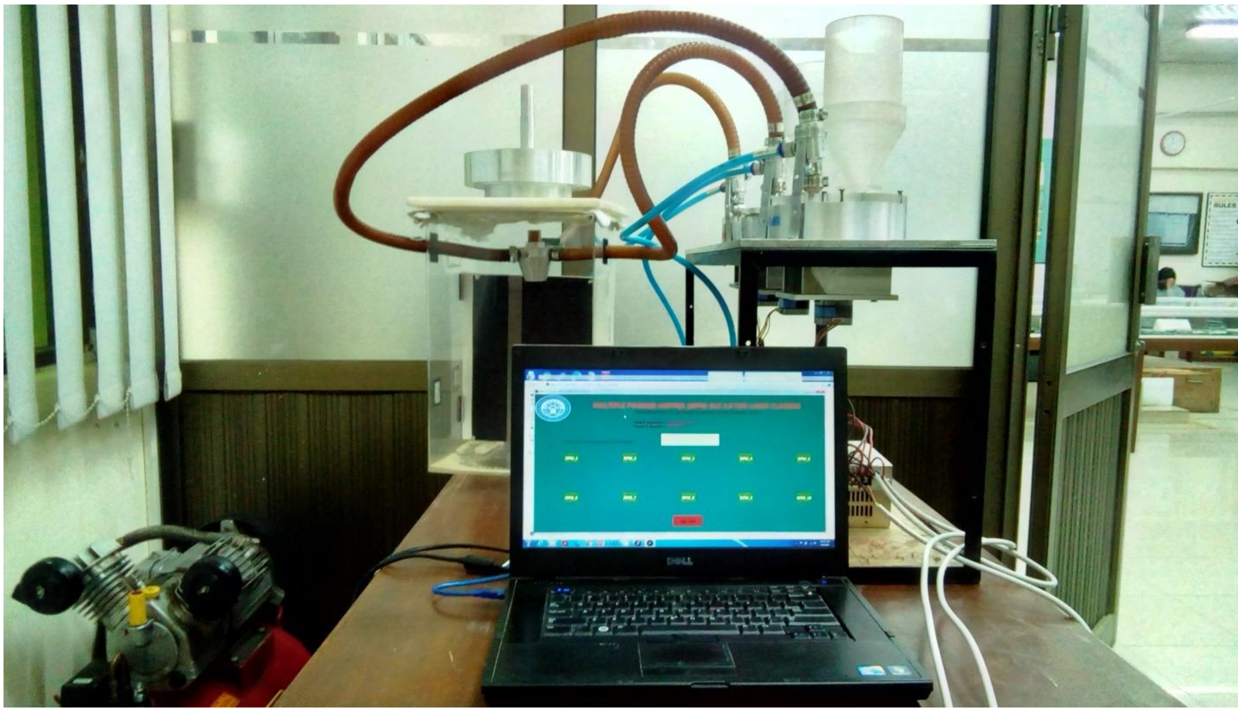


Figure 26 Integration of Co-axial nozzle and MPH

3.11 Phase-III Testing of Entire System

The final setup as shown in figure 27, was tested with silica sand, poppy seeds and other organic particles. At initial phases few problems were faced due to hindrance in disc rotations and it was concluded that the material inside the hopper containers was not filtered properly. Therefore, silica sand was filtered through 210 micron mesh screen. And poppy seeds were filtered through 300 microns mesh screen. The equipment was made ready for 2 types of experiment:

a) To confirm relationship of powder mass flow rate with change in disc RPM.
b) To confirm behavior of powder stream concentration at the nozzle exit due change in disc RPM.

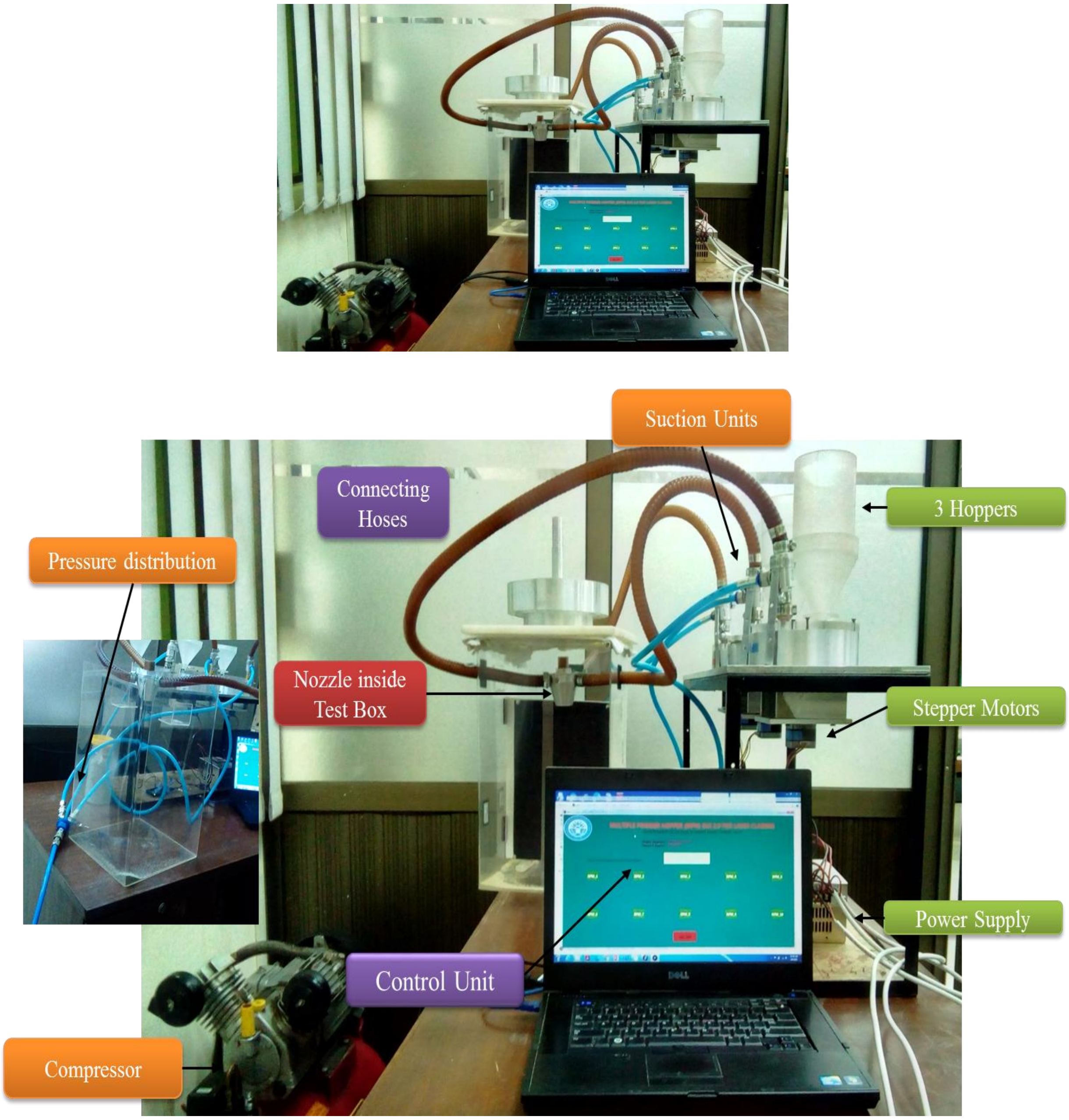


Figure 27 Testing Equipment Setup

CHAPTER 4: EXPERIMENTATION AND RESULTS

As discussed in last chapter, the complete system was used to conduct 2 type of experiments as:

1. To confirm relationship of powder mass flow rate with change in disc RPM
2. To check behavior of powder stream concentration at nozzle exit due change in disc RPM

4.1 Phase-III Final Experiment Part I

Recording of Results

The mass flow rate of multi powder hopper machine was recorded at two, four, six, eight and ten revolutions per minute. Three DC motors were used for internal mixing and slowing down the speed of powder flow from the hopper containers. Three experiments were conducted against each RPM for particular powder. Consequently, accumulating to total of 15 experiments. The experimental conditions were kept same for all the 15 observations. The working pressure of compressor was kept 1.7 bar through regulator. A stop watch was used for recording of time. The total mass of powder collected in certain amount of time is weighed on kitchen weighing machine. After that the mass flow rate is measured in gram/second. Eventually, the experiments were conducted and result are plotted in graph at figure 28 and reading data is in table 5.

Experiment No	RPM	Weight with measuring container	Actual weight	Time	Time in seconds	Rate in gram/second	Average Rate
1	2	68	45	1:35.54	95.54	0.471007	0.479796
2	2	69	46	1:35.84	95.84	0.479967	
3	2	70	47	1:36.23	96.23	0.488413	
4	4	113	90	1:35.67	95.67	0.940734	0.952521
5	4	114	91	1:35.45	95.45	0.953379	
6	4	115	92	1:35.49	95.49	0.963452	
7	6	156	133	1:35.64	95.64	1.390632	1.376691
8	6	154	131	1:35.58	95.58	1.37058	

9	6	154	131	1:35.70	95.7	1.368861	
10	8	194	171	1:35.65	95.65	1.787768	1.774175
11	8	173	150	1:24.40	84.4	1.777251	
12	8	191	168	1:35.59	95.59	1.757506	
13	10	231	208	1:35.60	95.6	2.175732	2.168607
14	10	231	208	1:35.62	95.62	2.175277	
15	10	229	206	1:35.60	95.6	2.154812	

Table 5 Experiment Data Sheet

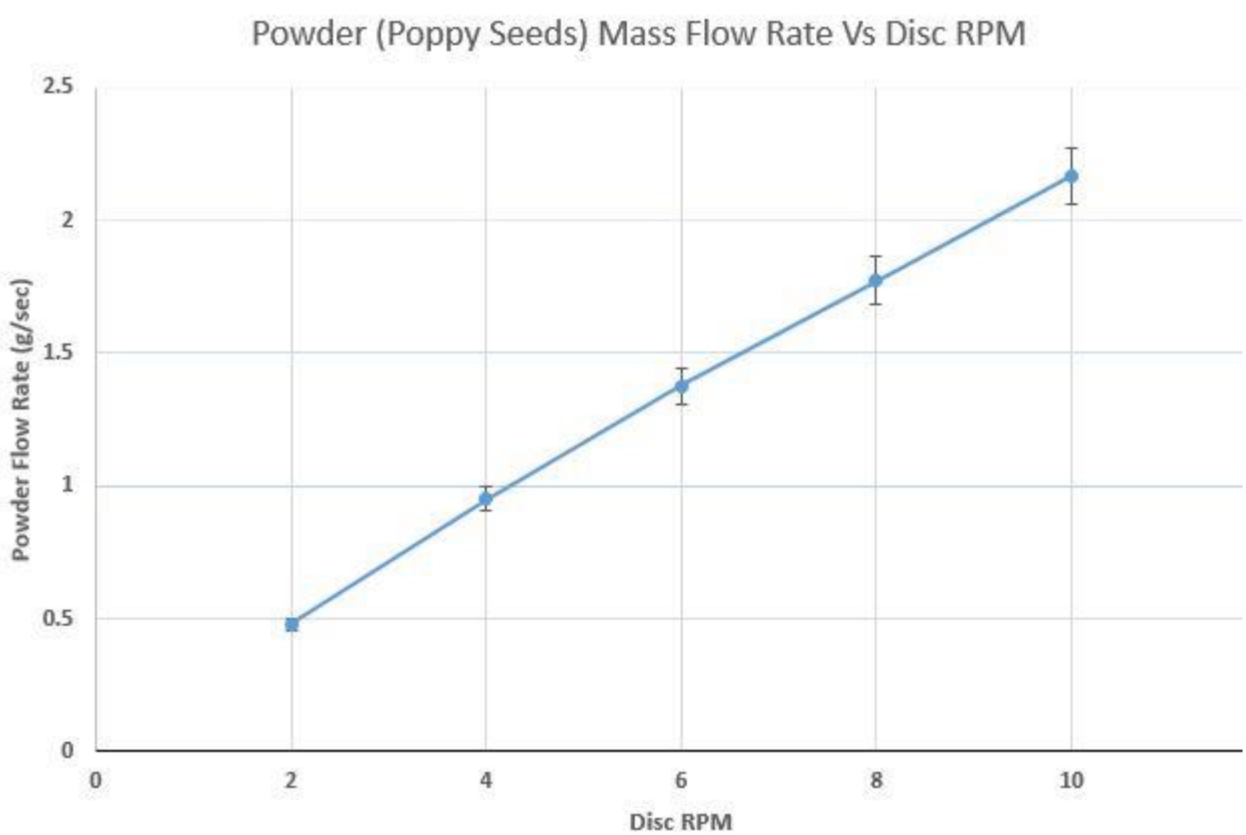


Figure 28 Graph of Mass Flow Rate Vs RPM

The figure 29 shows the complete system during experimentation. In our experiments, RPM is responsible for change in mass (dm) and rest everything was kept constant i.e density of particles, area of the suction pipe, Suction pressure, size of nozzle entrance connectors etc

$$\dot{m} = \frac{dm}{dt}$$

$\dot{m}$ = Mass flow rate

dm = Change in mass

dt = change in time = T1 - To

T1= Final time when RPM stops

To = Time at start of RPM

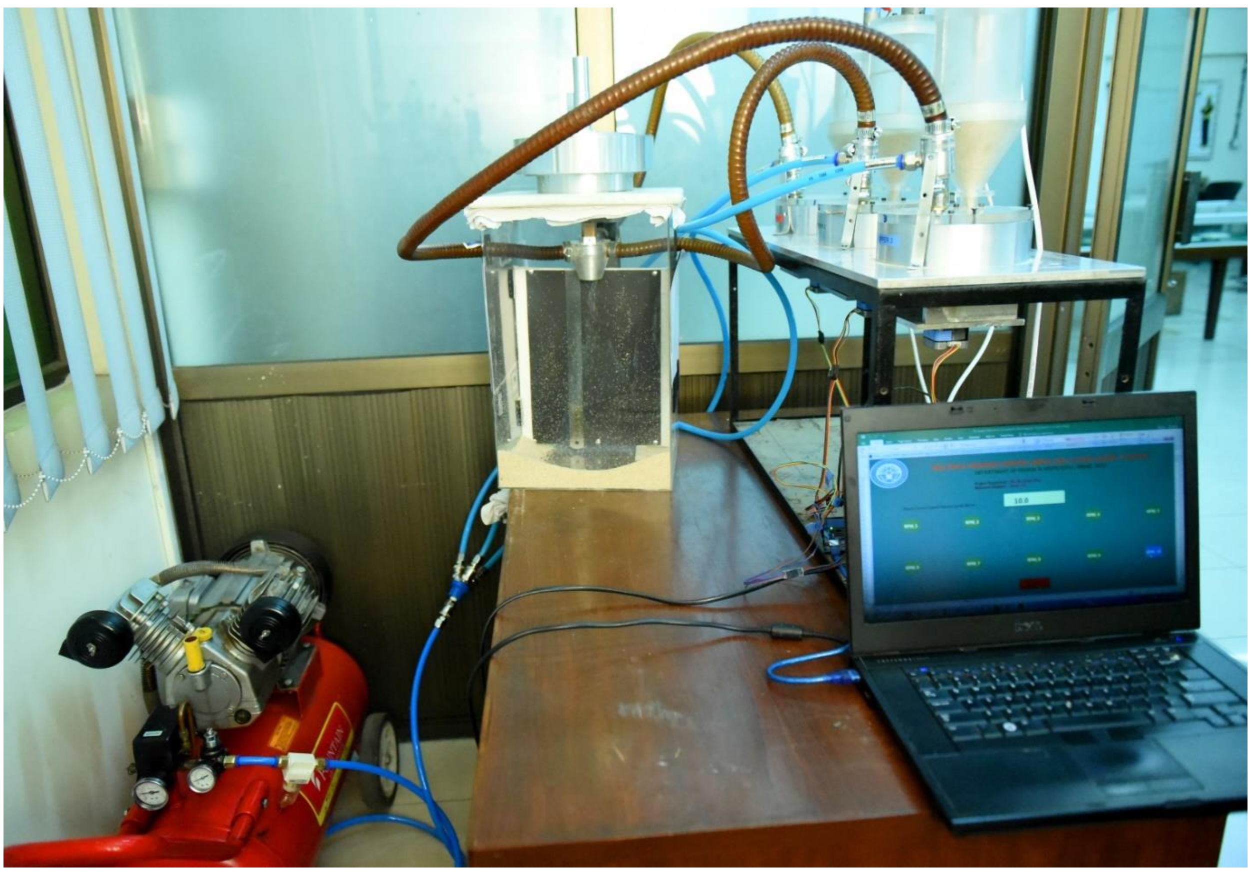


Figure 29 Complete setup during experimentation

4.2 Phase-III Final Experiment Part II

In order to measure the change in focus point of the nozzle with change in RPM, a black sheet with measuring scale was placed 12mm behind the nozzle, as shown in figure 30. A DSLR camera was used with the help of official photographer of NUST. The details of camera at time of taking photographs are appended in table 6.

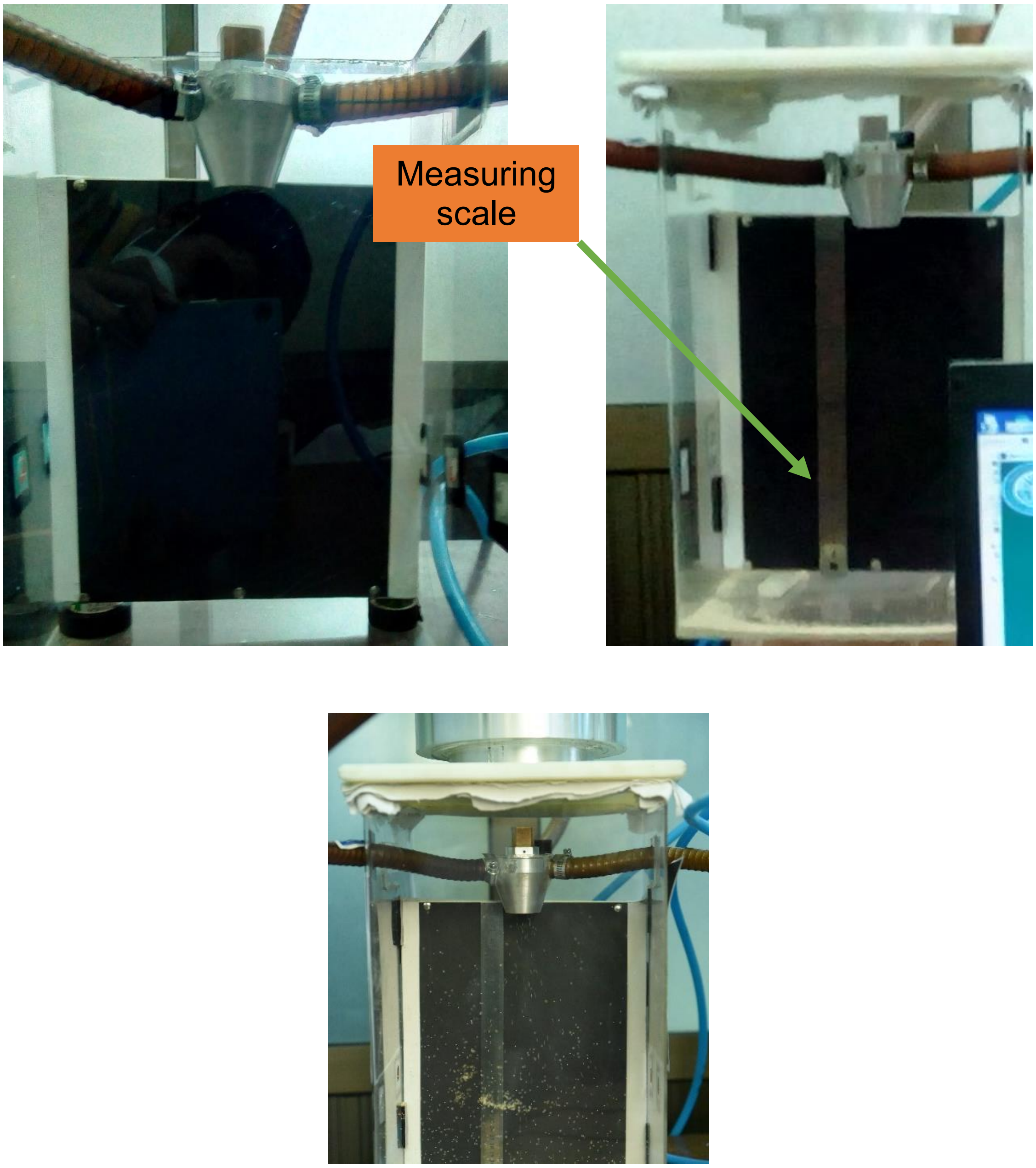


Figure 30 Experimentation setup for Measuring focus Point

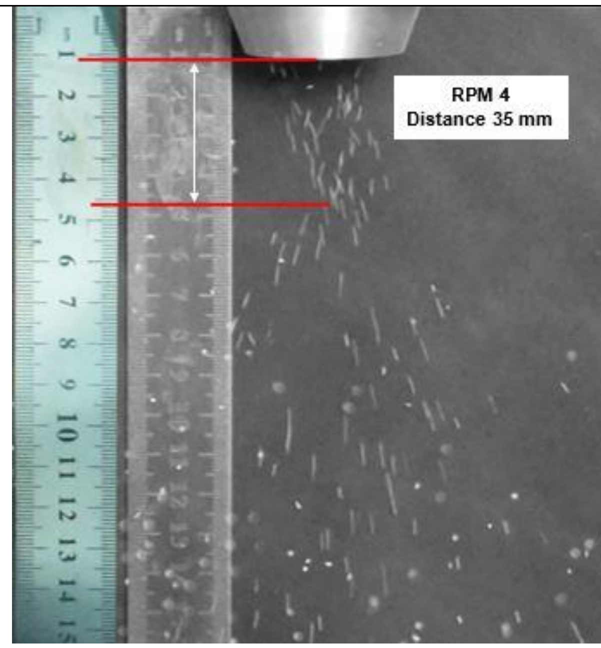
Camera Maker	Nikon
Camera Model	Nikon D750
F-stop	f/2.8
Exposure time	1/1000 sec
ISO speed	ISO-12800
Focal length	70 mm
Max aperture	3

Metering mode	Pattern
35mm focal length	70

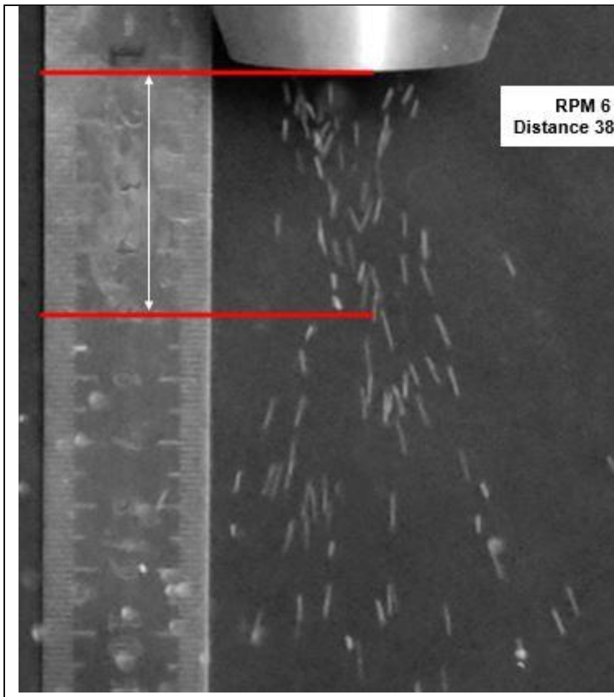
Table 6 Details of Camera at the time of Shots

The images were captured at two, four, six, eight and ten RPM as shown in table 7. Table 8 tells the change in distance from nozzle outlet (reference point) to the focus point with respect to change in RPM.

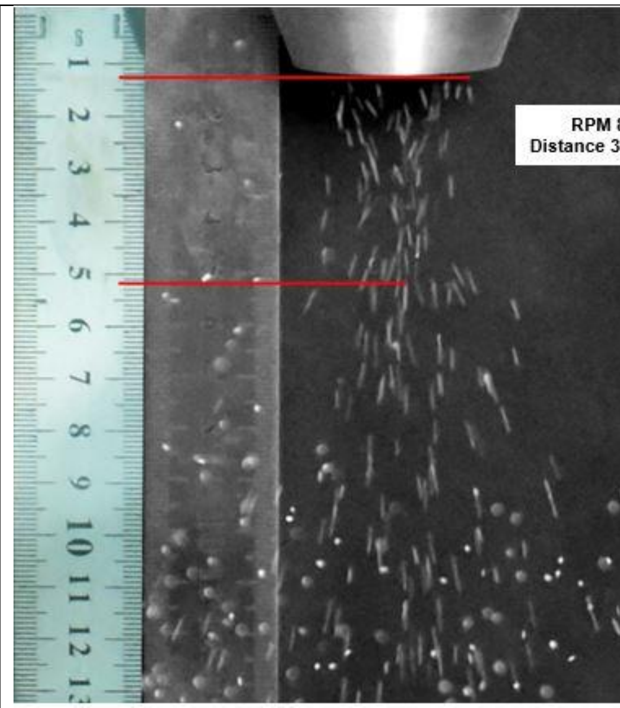
2 RPM



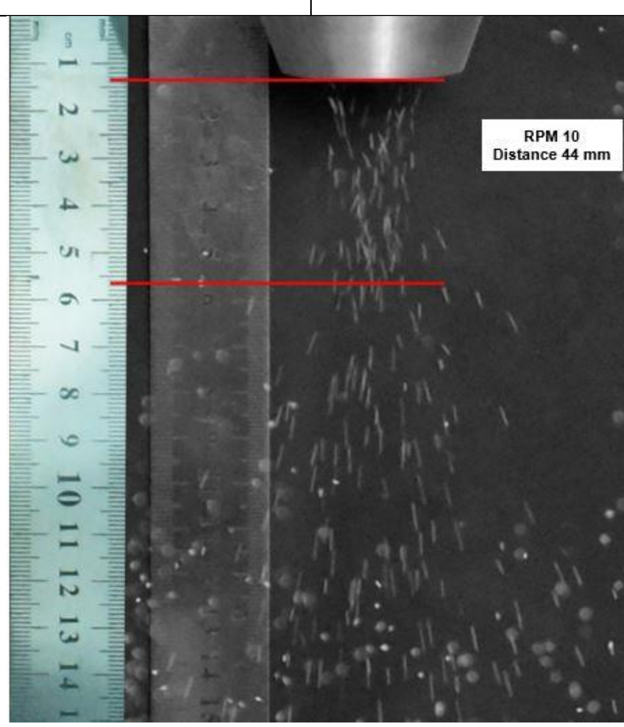
4 RPM



6 RPM



8 RPM



10 RPM

Table 7 Images of Nozzle Focus Point at different RPMs

RPM	Focus Point observed from Nozzle
2	28 mm
4	35 mm
6	38 mm
8	39 mm
10	44 mm

Table 8 Details of Focus Point Change

Proposed Feeding System

1. Powder mass flow rate has a direct relation with disc RPM in our system.
2. During the experiments we figured out certain difficulties in powder feeding system and based on that we have also proposed another feeding system.
3. This is different from other feeding systems which are used by past researchers and is based on horizontal feeding approach.
4. The advantage of this system will be that all size of powder particles can be used in this system without any modifications.

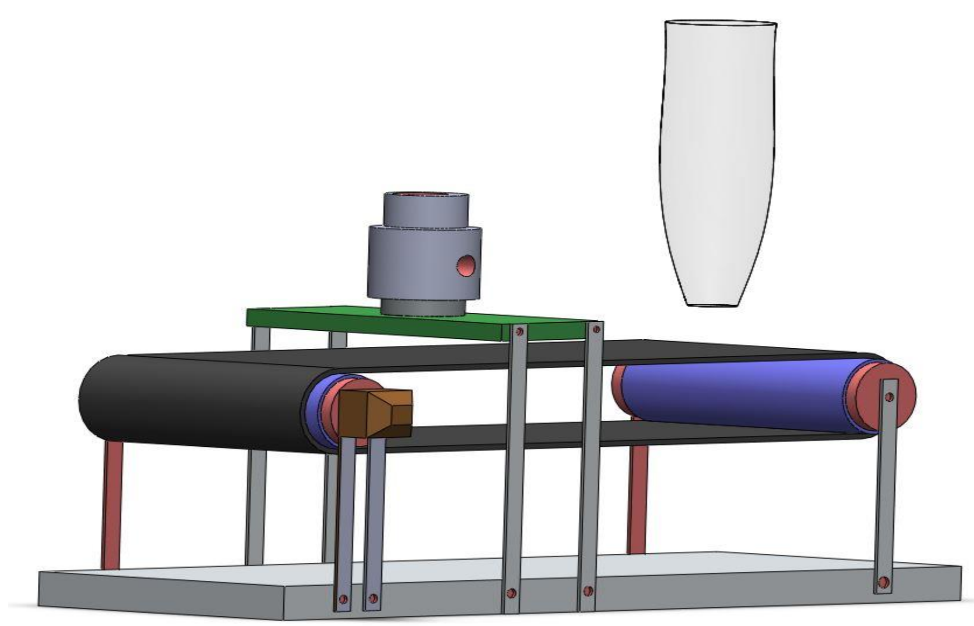


Figure 31 Proposed Feeding system

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

CONCLUSION

1. Powder mass flow rate has a direct relation with disc RPM.
2. The concentration of powder stream increase with change in disc RPM.
3. The point of powder stream concentration also increase with increase in disc RPM.
4. The variation in flowrate of supplied powders highlight the capability of multi-powder feeder machine to manufacture functionally graded materials.
5. The developed MPH and Co-axial nozzle setup can be used for training purpose and can enlighten the students about functioning of laser cladding.
6. The applications of Laser Metal Deposition (LMD) in favor of mankind are vast and necessities high level of research in low equipment cost especially for under develop countries like Pakistan.

RECOMMENDATIONS

1. The newly proposed feeding system can be worked upon separately and a patent may be applied for the new design of feeding system.
2. The efforts can be made to develop automatic control of nozzle head.
3. Further improvement in capturing of focus point can be undertaken for detailed analysis of powder stream.
4. The effect of change in suction unit settings on powder mass flow rate can be studied separately.
5. The flow of powder from the co-axial nozzle can be simulated on COMSOL or other CFD software as a separate study.
6. The test box can be improved further with incorporation of more advanced filters for testing of metallic powder.
7. Present design of multi-powder feeder can be used in pharmaceutical and food related projects.
8. The multi-powder feeder machine can supply powders at variable flowrates. The supplied powders should be imparted the laser treatment for observing the effects of laser cladding.

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Modification, Integration and Testing of Multi Powder Hopper with Co-Axial Nozzle for Laser Cladding

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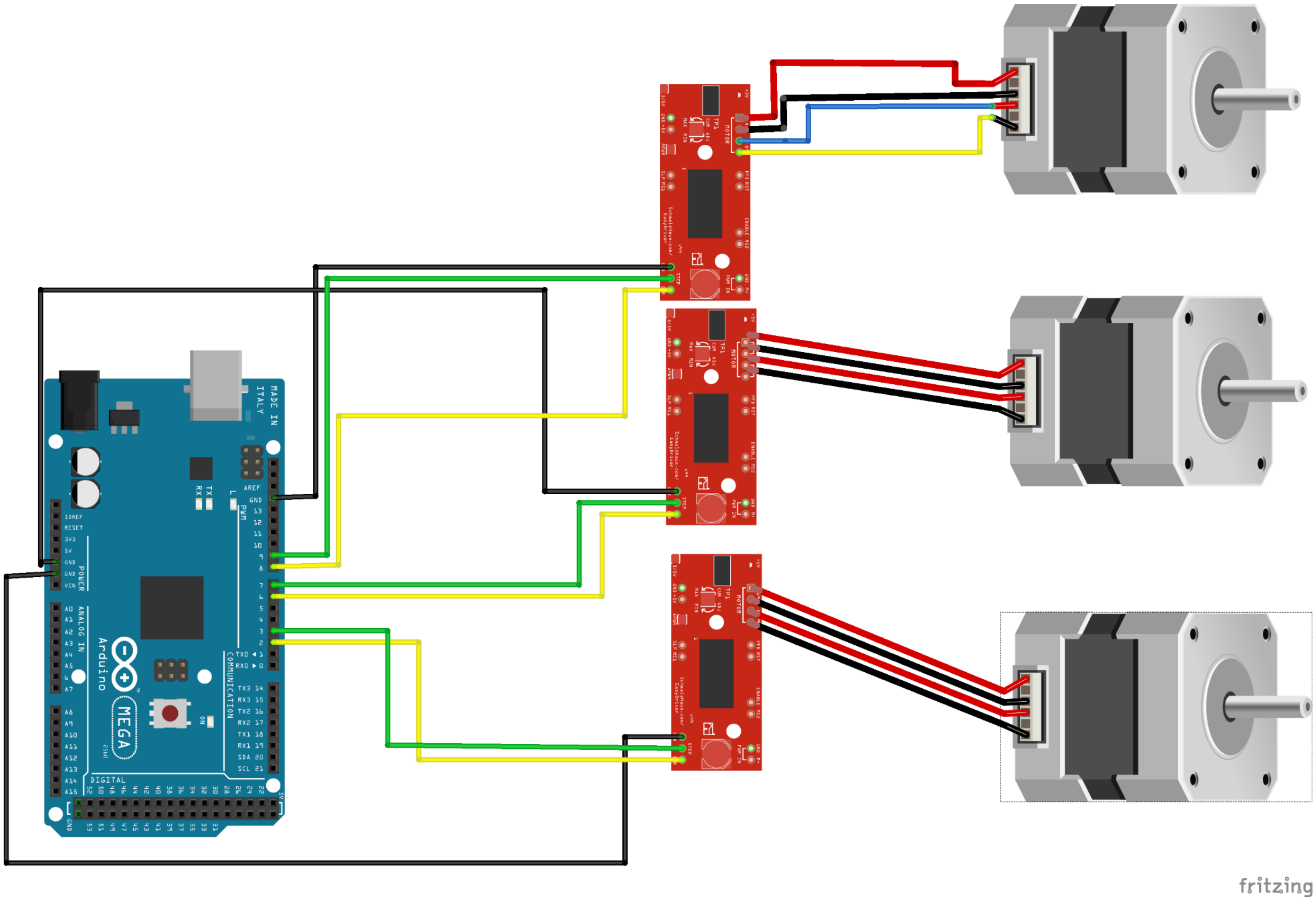
Complete Circuit Diagram



Arduino Code

3_Easy_Driver_GUI_Arduino_Mega §

```
#include <AccelStepper.h>
#define MotorInterfaceType 1
int val;
int a = 267;  // Steps per second for 10 RPM
AccelStepper stepper1 = AccelStepper(MotorInterfaceType, 9,8);//(MotorInterfaceType,Step, Dir)
AccelStepper stepper2 = AccelStepper(MotorInterfaceType, 7,6);
AccelStepper stepper3 = AccelStepper(MotorInterfaceType, 3,2);
void setup() {
  // Set the speed in  maximum steps per second

  stepper1.setMaxSpeed(1000);
  stepper2.setMaxSpeed(1000);
  stepper3.setMaxSpeed(1000);
  Serial.begin(115200);
}
void loop() {
//  Set the speed of the motor in steps per second
  if (Serial.available()) {
    val = Serial.read () ;
 }
 if (val == 250){
   val = a ;//RPM 10
   }
//else if (val == 18){
  //val = b ;//RPM 12
//}A
  stepper1.setSpeed(val);
  stepper2.setSpeed(val);
  stepper3.setSpeed(val); //For User it will be set in RPM 450 steps give 16.94 RPM
  // Step the motor with constant speed as set by setSpeed():
  stepper1.runSpeed();
  stepper2.runSpeed();
  stepper3.runSpeed();
 }
```

Calculation of Motor RPM

RPM of NEMA 17	STEPS Per Second
1	26.66
2	53.33
3	80
4	106.66
5	133.33
6	160
7	186.66
8	213.33
9	240
10	266.66

Processing 3.0 Code

sketch_3_Stepper_Motor_Speed_Control_with_Easy_driver

```
import controlP5.*;
import processing.serial.*; // when we add any value in GUI it will go the the arduino through serial
Serial port;
ControlP5 cp5;
PFont font; //for enlarging the font size
PImage img;

int x,y,z,a,b,c,d,e,f,g,t;
String h;
String Rev = "";
float i,j,k,l,m,n,o,p,q,r,s;

void setup(){
   img = loadImage("nust1.jpg");

  size(1500,700); //(width,height)

  printArray(Serial.list()); //prints all available Serial port

  port = new Serial(this,"COM5",115200);
                                                                                  //lets add button to the window

  cp5 = new ControlP5(this);
  font = createFont("Ebrima bold",20); // custom fonts for button and title

  cp5.addButton("RPM_1") //red is the name of button
     .setPosition(150,300) // x and y coordinates of upper left corner of  button
     .setSize(80,50) //(width, height) of button
     .setFont(font)
     .setColorBackground(color(50, 113, 20));
     x = 27 ; // 48 for arduino (val =27, a=27)


  cp5.addButton("RPM_2") //red is the name of button
  .setPosition(450,300) // x and y coordinates of upper left corner of  button
       .setSize(80,50) //(width, height) of button
       .setFont(font)
       .setColorBackground(color(50, 113, 20));

     y = 53; //53 for arduino

  cp5.addButton("RPM_3")//red is the name of button
  .setPosition(750,300)// x and y coordinates of upper left corner of  button
```

```
        .setSize(80,50) //(width, height) of button
        .setFont(font)
        .setColorBackground(color(50, 113, 20));
      z = 80; // 55 for arduino (55+25 = 80)

   cp5.addButton("RPM_4")//red is the name of button
   .setPosition(1050,300)// x and y coordinates of upper left corner of  button
        .setSize(80,50) //(width, height) of button
        .setFont(font)
        .setColorBackground(color(50, 113, 20));
      a = 107 ; //51 for arduino (51+57=107)

      cp5.addButton("RPM_5")//red is the name of button
   .setPosition(1350,300)// x and y coordinates of upper left corner of  button
        .setSize(80,50) //(width, height) of button
        .setFont(font)
        .setColorBackground(color(50, 113, 20));
      b = 133; //49 for arduino (49+84=133)

       cp5.addButton("RPM_6")//red is the name of button
   .setPosition(150,500)// x and y coordinates of upper left corner of  button
        .setSize(80,50) //(width, height) of button
        .setFont(font)
        .setColorBackground(color(50, 113, 20));
      c = 160; // 50 for arduino (50 +110 = 160)

      cp5.addButton("RPM_7")//red is the name of button
   .setPosition(450,500)// x and y coordinates of upper left corner of  button
        .setSize(80,50) //(width, height) of button
        .setFont(font)
        .setColorBackground(color(50, 113, 20));
      d = 187; //52 for arduino (52+135 =187)

      cp5.addButton("RPM_8")//red is the name of button
   .setPosition(750,500)// x and y coordinates of upper left corner of  button
        .setSize(80,50) //(width, height) of button
        .setFont(font)
        .setColorBackground(color(50, 113, 20));
      e = 213; //54 for arduino (54 +159 =213)

       cp5.addButton("RPM_9")//red is the name of button
   .setPosition(1050,500)// x and y coordinates of upper left corner of  button
```

```
      .setSize(80,50) //(width, height) of button
      .setFont(font)
      .setColorBackground(color(50, 113, 20));
     f = 240; //56 (56 + 184 = 240)

     cp5.addButton("RPM_10")//red is the name of button
  .setPosition(1350,500)// x and y coordinates of upper left corner of  button
      .setSize(80,50) //(width, height) of button
      .setFont(font)
      .setColorBackground(color(50, 113, 20));
     g = 250; // 57 for arduiono (57 + 210 )


  cp5.addButton("All_OFF")
     .setPosition(715,620)
     .setSize(150,50)
     .setFont(font)
     .setColorLabel(0)
     .setColorBackground(color(200, 0, 0));
     t=0;
}
void draw(){
  button();
  display();
  mousePressed();
}
void button(){
     background(10,100,80) ; //background colour (0 to 255) or (r,b,g)
        //Lets give title
      fill(250,55,0); //(text colour(r,g,b)
      font = createFont("Ebrima bold",35);
      textFont(font);
       text("MULTIPLE POWDER HOPPER (MPH) GUI 2.0 FOR LASER CLADING",300,70); //("text", x-cordinate, y-cordinate)
       //Line 2
       fill(55,55,0); //(text colour(r,g,b)
       font = createFont("Ebrima bold",25);
       textFont(font);
        text("DEPARTMENT OF DESIGN & MNFG ENGG, SMME, NUST",510,100);
        //Line 3
        fill(105,0,10); //(text colour(r,g,b)
       font = createFont("Ebrima bold",18);
       textFont(font);
```

```
        text("Project Supervisor :",510,150);
        //Line 3 Remaining
        fill(155,0,55); //(text colour(r,g,b)
       font = createFont("Ebrima bold",18);
       textFont(font);
        text("DR. Mushtaq Khan",680,150);
        //Line4
        fill(105,0,10); //(text colour(r,g,b)
       font = createFont("Ebrima bold",18);
       textFont(font);
        text("Research Student :",510,170);
        //Line 4 Remaining
        fill(155,0,55); //(text colour(r,g,b)
       font = createFont("Ebrima bold",18);
       textFont(font);
        text("Ahsan Ali",680,170);
        //Line 5
        fill(0,0,0); //(text colour(r,g,b)
       font = createFont("Ebrima",18);
       textFont(font);
        text(" Please Choose Stepper Motors Speed Below:",150,250);
      image(img,0,0,width/8, height/5);
 }
void display(){
  fill(183,255,145);//entry colour
 rect (650,200,300,60);
 fill(10, 3, 40);
 font = createFont("Ebrima bold",35);
       textFont(font);
 text(Rev, 700, 250);
}
 void mousePressed(){
 if (mousePressed){
   if(mouseX>150&&mouseX<230&&mouseY>300&&mouseY<350){
   i = 1*1;
   Rev = str(i) ;// RPM 1
 }
  else if(mouseX>450&&mouseX<530&&mouseY>300&&mouseY<350){
   j = 2*1;
   Rev = str(j) ; // RPM 2
  }
 else  if(mouseX>750&&mouseX<830&&mouseY>300&&mouseY<350){
```

```
    k = 3*1;
    Rev = str(k) ; // RPM 3
  }
   else if(mouseX>1050&&mouseX<1130&&mouseY>300&&mouseY<350){

    l = 4*1;
    Rev = str(l) ; // RPM 4
  }
    else if(mouseX>1350&&mouseX<1430&&mouseY>300&&mouseY<350){

    m = 5*1;
    Rev = str(m) ; // RPM 5
  }
   else if(mouseX>150&&mouseX<230&&mouseY>500&&mouseY<550){

    n = 6*1;
    Rev = str(n) ; // RPM 6
  }
    else if(mouseX>450&&mouseX<530&&mouseY>500&&mouseY<550){
    o = 7*1;
    Rev = str(o) ; // RPM 7
  }
   else if(mouseX>750&&mouseX<830&&mouseY>500&&mouseY<550){
    p = 4*2;
    Rev = str(p) ; // RPM 8
  }
  else if(mouseX>1050&&mouseX<1130&&mouseY>500&&mouseY<550){
    q = 3*3;
    Rev = str(q) ; // RPM 9
  }
    else if(mouseX>1350&&mouseX<1430&&mouseY>500&&mouseY<550){
        r = 5*2;
        Rev = str(r) ; // RPM 10
  }
    else if(mouseX>715&&mouseX<620&&mouseY>620&&mouseY<670){
    Rev = "OFF" ; // All OFF
  }
}
} //lets add  some function to our buttons //so when we press any button, it sends particular char over serial port
void RPM_1(){
  port.write(x);
  print(x);
```

```
}
void RPM_2(){
  port.write(y);
  println(y);
}
void RPM_3(){
  port.write(z);
  println(z);
}
void RPM_4(){
  port.write(a);
  println(a);
}
void RPM_5(){
  port.write(b);
  println(b);
}
void RPM_6(){
  port.write(c);
  println(c);
}
void RPM_7(){
  port.write(d);
  println(d);
}
void RPM_8(){
  port.write(e);
  println(e);
}
void RPM_9(){
  port.write(f);
  println(f);
}
void RPM_10(){
  port.write(g);
  println(g);
}
void All_OFF(){
  port.write("h");
  print("h");
}
```

VACUUM PUMP DATA SHEET

ZH 20 - B ▢ -X185

Passage diameter

Symbol	mmø
10	13
20	21.6
30	30
40	42

Bracket

Nil	Without bracket
B	With bracket

Dust bag

Nil	Without dust bag
D*	With dust bag (Supplied with product)

* Hose band attached

SP
ZCUK
AMJ
AFJ
AMV
ZH -X185
Related Products

⚠Warning

1. Because suctioned matter is ejected together with exhaust, do not direct an exhaust port at a person or equipment.
2. Do not use in an atmosphere having corrosive gases, chemicals, sea water, water steam, or where there is direct contact with any of these.

⚠Refer to back page 50 for Safety Instructions and pages 49 to 51 for Vacuum Equipment Precautions.

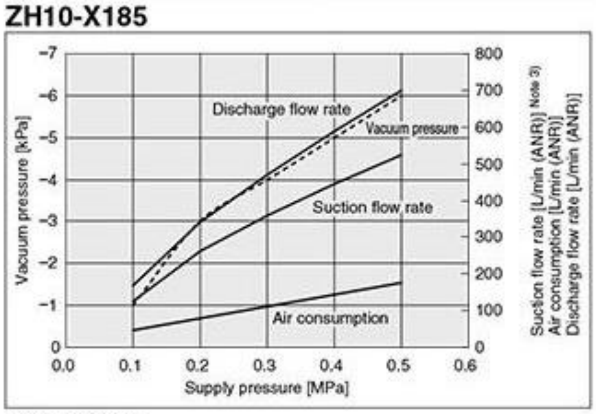
Specifications

Model	ZH10-X185	ZH20-X185	ZH30-X185	ZH40-X185
Body material	Aluminum alloy			
Seal material	NBR			
Bracket material	Steel			
Dust bag material	Polyester			
Hose band material	Stainless steel			
Passage diameter	ø13	ø21.6	ø30	ø42
C [dm³/(S·bar)] (Effective area [mm²]) Note 1)	0.49 (2.46)	1.04 (5.19)	1.97 (9.86)	3.69 (18.47)
Fluid	Air			
Supply pressure range	0 to 0.7 MPa			
Ambient and fluid temperature (°C)	–5 to 80 (with no freezing or condensation)			
Weight (g) Note 2)	92 (101)	417 (436)	929 (990)	1847 (1966)
Bracket assembly	ZH-BK1-10-A	ZH-BK1-20-A	ZH-BK1-30-A	ZH-BK1-40-A
Dust bag assembly	ZH-DB1-10-A	ZH-DB1-20-A	ZH-DB1-30-A	ZH-DB1-40-A

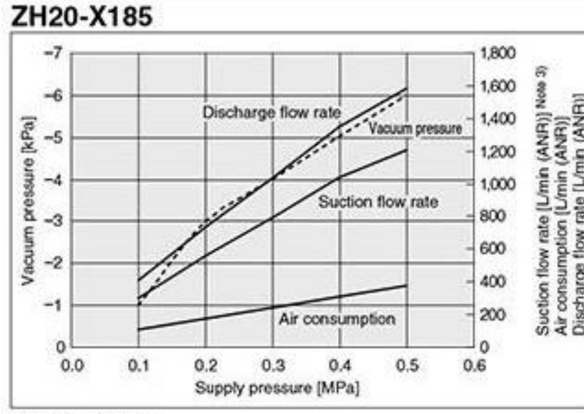
Note 1) The C value as well as the effective area is a theoretical value. Note 2) ( ): Weight including the bracket

Exhaust Characteristics

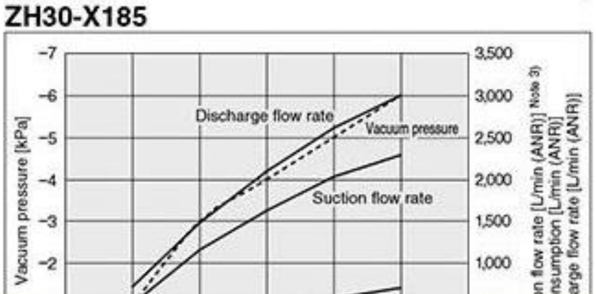
ZH10-X185



ZH20-X185



ZH30-X185



ZH40-X185