UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Faculty of Mechanical Engineering

DESIGN, DEVELOPMENT AND PERFORMANCE OF A LOW COST THREE-DIMENSIONAL METAL PRINTER

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DESIGN, DEVELOPMENT AND PERFORMANCE OF A LOW COST THREE-DIMENSIONAL METAL PRINTER

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in fulfillment of the requirements for the degree of Master of Science
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DECLARATION

I declare that this thesis entitled " Design, Development and Performance of A Low Cost Three-Dimensional Metal Printer" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature	:	....
Name	:	Nor Ana binti Rosli
Date	:	....

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APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Master of Science in Mechanical Engineering

Signature	:	…………………………………...
Supervisor Name	:	Ir. Dr. Mohd Rizal bin Alkahari
Date	:	…………………………………...

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DEDICATION

"To my beloved family"

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ABSTRACT

3D printing or additive manufacturing (AM) for metallic component is one of the most promising processes that offers freedom to produce an intricate design in a single step. The metal AM process is characterised by high productivity, high energy efficiency, and low raw material cost. A functional metal part can be directly built by using AM process. This increases productivity while enabling reduction in cost and time. The technology is a relatively new and emerging technology. Recently, the growing demand in metal-based material application is utilised in 3D printing. The laser-based system is commonly used for commercial 3D metal printing. However, the price of commercial metal-based 3D printer systems is relatively expensive. Moreover, this drawback has severely restricted the technology access to small and medium industry applications. This study develops a new low-cost 3D metal printing machine by using a wire and arc additive manufacturing process. In other to reduce cost, alternative heat sources were used and a new system utilising an open source was developed. The design and development processes on the hardware and electronic components were described and evaluated. A brief description on basic construction, process, and operations to handle the low-cost 3D metal printer, were presented. This study also presents the total bill for material, connection of electronic parts, and illustration of the experimental setup. Besides that, to test the newly developed machine performance, printed samples were manufactured and tested. In this context, two different heat sources were used, which were the metal inert gas (MIG) welding and plasma arc welding (PAW) process. The experimental setup for both heat sources was described. The sample's accuracy and structure were examined and compared with the computer aided design (CAD) data. In order to obtain more information about the printed bead geometry, the specimen was cut cross-sectionally and captured by using a scanning electron machine (SEM). As a result, two different findings can be found by using two different heat sources. Nonetheless, the result confirms that the newly developed low-cost 3D metal printer with wire feed AM process is relatively acceptable to produce 3D metal structures.

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ABSTRAK

Percetakan 3D atau pembuatan secara tambahan untuk menghasilkan komponen logam adalah salah satu proses yang menjanjikan kebebasan dalam menghasilkan reka bentuk yang rumit dengan satu langkah. Pembuatan secara tambahan untuk bahan logam dicirikan sebagai tinggi produktiviti, tinggi kecekapan tenaga dan kos bahan mentah yang rendah. Bahagian logam yang berfungsi juga boleh dihasilkan secara terus menggunakan proses pembuatan secara tambahan dan ini dapat meningkatkan produktiviti selain membolehkan pengurangan kos dan masa. Baru-baru ini, permintaan penggunaan percetakan 3D untuk bahan logam semakin meningkat. Sistem berasaskan laser biasanya digunakan untuk percetakan logam 3D komersial. Walaubagaimanpun, harga sistem percetakan 3D komesial yang berasaskan logam agak mahal. Tambahan pula, kelemahan ini telah menghadkan penggunaan teknologi ini untuk kegunaan industri kecil dan sederhana. Kajian ini membangunkan mesin percetakan logam 3D berkos rendah dengan menggunakan wayar untuk pembuatan secara tambahan. Untuk mengurangkan kos, sumber haba alternatif telah digunakan dan sistem baru menggunakan sistem terbuka telah dibangunkan. Proses mereka dan membangunkan komponen perkakasan dan elekronik telah dinilai dan diterangkan. Penerangan ringkas mengenai pembinaan asas, proses dan cara untuk mengendalikan percetakan logam 3D berkos rendah dibentangkan. Kajian ini juga membentangkan jumlah senarai bahan, penyambungan bahagian elektronik dan ilustrasi persediaan melakukan eksperimen. Selain itu, untuk menguji kecekapan mesin yagng baru dibangunkan ini, sampel logam 3D telah dicetak dan diuji. Dalam konteks ini, dua sumber haba digunakan iaitu kimpalan logam gas lengai dan kimplan. Persediaan eksperimen untuk kedua-dua sumber haba telah dijelaskan. Ketepatan dan struktur sampel diperiksa dan dibandingkan dengan rekabentuk bantuan komputer. Untuk mendapatkan lebih banyak maklumat tentang geometri yang dihasilkan, sampel telah dipotong secara rentas dan dilihat menggunakan mesin pengimbas elektronik. Keputusan menunjukkan dua hasil yang berbeza boleh didapati dengan menggunakan dua sumber haba yang berlainan. Walaubagaimanapun, keputusan mengesahkan bahawa pencetak logam 3D berkos rendah yang baru dibangunkan ini dengan proses pembuatan secara penambahan wayar boleh diterima dalam menghasilkan struktur logam 3D.

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LIST OF SYMBOLS

$\sum$	-	Summation
w_i	-	Weighting factor
n	-	Number of evaluation
V	-	Voltage applied
I_{max}	-	Maximum current [A]
spr	-	Step per revolution
L	-	Stepper motor inductance

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LIST OF ABBREVIATIONS

AM	-	Additive Manufacturing
CAD	-	Computer Aided Design
CNC	-	Computer Numerical Control
DED	-	Direct Energy Deposition
FDM	-	Fused Deposition Modelling
GMAW	-	Gas Metal Arc Welding
GTAW	-	Gas Tungsten Arc Welding
HAZ	-	Heat Affected Zone
LOM	-	Laminated Object Manufacturing
MAG	-	Metal Active Gas
MIG	-	Metal Inert Gas
PAW	-	Plasma Arc Welding
PTA	-	Plasma Tungsten Arc
SEM	-	Scanning Electron Microscope
SLS	-	Selective Laser Sintering
SOD	-	Stand Off Distance
STL	-	Standard Tessellation Language
TIG	-	Tungsten Inert Gas
WAAM	-	Wire Arc Additive Manufacturing
3D	-	Three-Dimensional

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LIST OF PUBLICATIONS

Journal Articles

N. A. Rosli, M. R. Alkahari, F. R. Ramli, S. Maidin, M. N. Sudin, S. Subramoniam, T, Furumoto, 2018. Design and Development of a Low-Cost 3D Metal Printer, *Journal of Mechanical Engineering Research and Development*, 41(3), pp. 47-54.

N. A. Rosli, M. R. Alkahari, F. R. Ramli, M. N. Sudin, S. Maidin, Single Track Formation of Plasma Wire Deposition Process, *Journal of Advanced Manufacturing Technology* (Accepted).

Intelectual Property

M. R. Alkahari, **N. A. Rosli,** F. R. Ramli, S. Maidin, S. Subramaniam, M. N. Sudin, "A Multimodal Three-Dimensional Printer and a Method for Printing a Metallic Component in Three Dimensions", Patent Application No. PI 2017/00097, filed Jan 10, 2017.

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LIST OF AWARDS

- Gold Award Universiti Teknikal Malaysia Melaka Exhibition (UTeMEX 2016)
- Bronze Award, International Research Conference and Innovation Exhibition (IRCIE 2016)
- Bronze Award Malaysia Technology Expo (MTE 2017)
- Bronze Award The International Conference and Exposition on Inventions by Institutions of Higher Learning (PECIPTA 2017)

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CHAPTER 1

INTRODUCTION

1.1 Background

Additive manufacturing (AM) process has gained attention in most manufacturing industries (Dilberoglu et al., 2017). The technology creates a part without using a machine as a tool to assist in production processes, therefore, saves a lot of time and money (Herderick, 2011). AM or 3D printing is a group of technologies that is used to build prototypes, physical models, and finished parts from 3D computer-aided design (CAD) data. (Udroiu and Nedelcu, 2011). This technology has developed rapidly and its effectiveness is proven, especially for designing and small production (Kruth et al., 1998; Galantucci et al., 2015).

AM technology also allows the fabrication of complex shapes directly from CAD data by using a layer by layer approach with minimum adjustment (Villalpando et al., 2014; Lanzotti et al., 2016). Furthermore, AM technology offers advantages in many applications as compared to the conventional machines, such as CNC. Although CNC machines are capable of producing products directly from CAD, but for complex shapes it is necessary to do multiple re-fixtures and recalibrate the procedure (Ding et al., 2015). A manufacturing process that use AM technology from virtual designs to ready-to-use parts is also lesser than the common process and conveniently allows the manufacturer to commercialise the product faster. Besides, this technology can create a single structure with complex shapes that are nearly impossible to be built by using traditional approaches.

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The evolution of 3D printer technology is now easily accessible through the Internet, and due to that, open design can also be developed. In fact, the increase in 3D printing applications has drawn manufacturers and individuals to improve the machine, especially for fabrication processes. (Galantucci et al., 2015). AM technology has great potential to improve the processing industry in the future. Furthermore, a 3D printing machine can be developed by using an open source. The presence of open source allows the building of a 3D printer with a low fabrication cost. (Galantucci et al., 2015). Available examples of open source models are RepRap, fab@home, and Ultimaker. Anyone can use the open source systems, redistribute it, study, and modify the source code without restriction since the project is an open source system. (Pearce, 2013). Adrian Boyer from the University of Bath, in United Kingdom started to establish the 3D printer capability to repeat a significant number of its structural component (Anzalone et al., 2013). RepRap or rapid self-replicate prototyping is the most successful project in open source systems. The estimated number of RepRap users had increased from 4 to 4,500 between 2008 to 2010 (Jandric et al., 2004).

Recently, the understanding of AM technology for metal-based material processing has significantly improved due to the increase in demand (Qian et al., 2016). The technology has undergone rapid progress and its usage has emerged in some applications, such as automotive engines, manufacturing tools, power tools, and aircraft assemblies (Jurrens and Energetics Incorporated, 2013). There is a diversed selection of producing metal components by using AM technology processes that are commercially available. Process such as selective laser sintering (SLS) (Khaing et al., 2001), direct metal deposition (Dinda et al., 2008), shape metal deposition (Baufeld et al., 2010), electron beam melting (Brandl et al,, 2011), and the most recent plasma deposition (Martina et al., 2012). However, the basic process involved in producing 3D products remains the same. The process starts with a CAD drawing. Then the file is converted to the .stl file format, Then the model is sliced and

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