Design and Implementation of a Computer-Controlled Work Station for Laser Welding Application

A Thesis
Submitted to the Council of the College of Sciences, University of Babylon in Partial Fulfillment of the Requirements for the Degree of Master of science in Physics

BY

Ra'id Majeed Bayee

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تصميم وإنجاز منظومة عمل مسيطر عليها حاسوبياً لتطبيقات اللحام بالليزر

رسالة مقدمة إلى مجلس كلية العلوم جامعة بابل وهي جزء من متطلبات نيل شهادة الماجستير في علوم الفيزياء
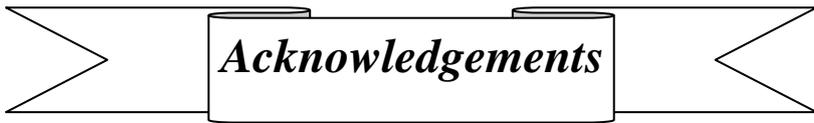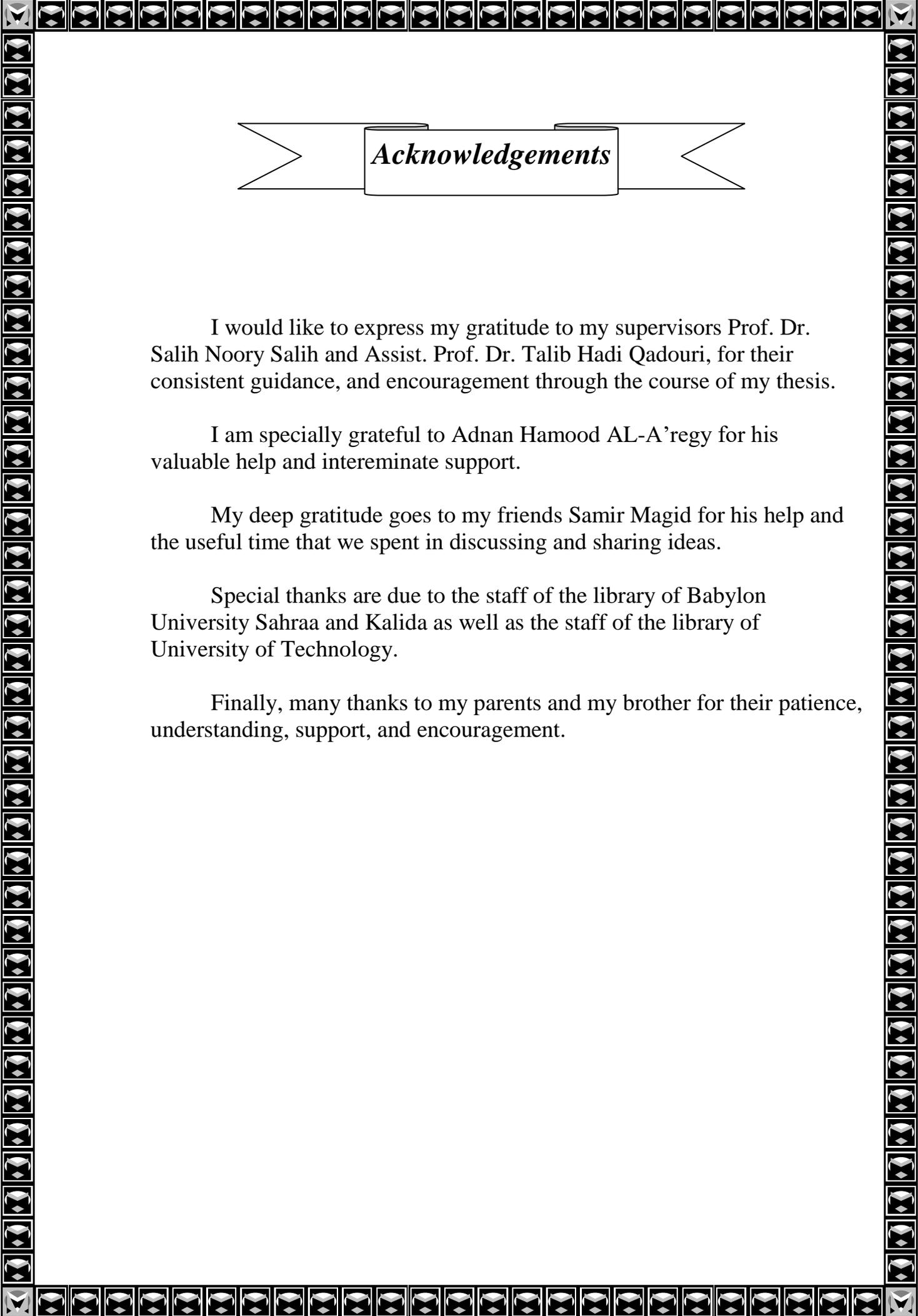
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رائد مجيد بيعي

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بسم الله الرحمن الرحيم

وَلِيَعْلَمَ الَّذِينَ أُوتُوا اَلْعِلْمَ أَنَّهُ اَلْحَقُّ مِنْ رَبِّكَ فَيُؤْمِنُوا بِهِ فَتُخْبِتَ لَهُ قُلُوبُهُمْ وَأَنَّ اَللهَ لَهَادِ الَّذِينَ أَمَنُوا إِلَى صِرَاطٍ مُسْتَقِيمٍ

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Abstract

In this work a computer controlling laser welding work station was designed and implemented. The design and implementation of the hardware and software components for controlling techniques were presented in details where, the open loop system technique, was selected to control the x and y axes of the work station deflection area (32*52cm) and to control the shutter of laser beam to control the duration of the weld.

The x and y axes was deflected by two stepping motors have a step angle (7.5°). To increasing the accuracy of the work station, the stepping motors was driving with two phase on mode. As a result, the step angle was decreased to (3.75°).

The accuracy of the work station is $(\pm 0.5\,\text{mm})$ and a maximum speed is (6 cm/sec) with a high stability.

The software program was made through C++ language operation under dos environment to perform the axes movement and shutter operation by designed the interfacing card.

الخلاصة

تم في العمل تصميم وإنجاز منظومة لأغراض اللحام باستخدام أشعة لليزر تتم السيطرة عليها بواسطة الحاسوب الشخصي عن طريق ربطها بلوح التوازي للحاسبة .

لقد تم تقديم عرض تفصيلي لتصميم المكونات المادية و البرامجيات المستخدمة للسيطرة على حركة المنظومة ، حيث اختيرت تقنية الحلقة المفتوحة للسيطرة عليها للمحورين السيني والصادي لمسافة (52سم) و(32سم) على التعاقب هذا بالإضافة إلى السيطرة على حركة غالق أشعة الليزر للتحكم بالفترة اللازمة للحام .

تتم حركة المنظومة على المحورين أعلاه بواسطة محركا خطوة (Stepping Motor) متساويا الخطوة والتي كان قدرها (7.5°) ولأجل زيادة دقه الحركة تم تقليص الخطوة الى النصف (3,75 °) باعتماد تقنية ازدواج الطور.

كانت دقة حركة المنظومة (± 0,5 ملم) عند أعلى سرعة حركه (6 سم/ثا) باستقرارية عالية .

استخدمت لغة C++ تحت نظام Dos في تصميم البرامجيات اللازمة للسيطرة على حركة المنظومة بالمحورين أعلاه إضافة إلى حركة غالق منظومة الليزر، لتتوافق مع لوح التداخل الذي تم تصميمه خصيصا لملائمة العمل .

Dedication

To everyone who is interested in this field of knowledge.

Ra'id Majeed

Content

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Certification

We certify that this thesis was prepared under our supervision at Babylon University as a partial requirement for the degree of Master of Science in physics.

<u>Supervisors:</u>

Signature:
Name: ***Dr. Talib Hadi Kadouri***
Title: Assist. Prof.
Address: University of Babylon
Date: /   / 2004

Signature:
Name: ***Dr. Salih Noory Salih***
Title: Prof.
Address: University of Technology
Date: /   / 2004

In view of the available recommendation, I forward this thesis for debate by the Examining Committee.

Signature:
Name: ***Dr. Talib Hadi Kadouri***
        (Head of the Physics Dep.)
Date: /   / 2004

Examining Committee Certificate

  We certify that we have read this thesis entitled " Design and Implementation of a Computer-Controlled Work Station for Laser Welding Application" and, as an Examining Committee, examined the student "Ra'id Majeed Sahib" in its content and that, in our opinion it meets the standards of a thesis for the degree of Master of Science in Physics.

Signature: Signature:
Name: **Dr. Mouayed Aziz Hasan**   Name*: **Dr. Adil Hameed Ahmad**
Title: Prof.   Title: Assist. Prof.
Address: University of Technology   Address: University of Technology
Date: /   / 2004   Date: /   / 2004
          (Chairman)   (Member)

                         Signature:
                         Name*: **Dr. Adnan Saleh**
                         Title: Assist. Prof.
                         Address: University of Baghdad
                         Date: /   / 2004
                                   (Member)

Signature: Signature:
Name*: **Dr. Talib Hadi Kadouri**   Name: **Dr. Salih Noory Salih**
Title: Assist. Prof.   Title: Prof.
Address: University of Babylon   Address: University of Technology
Date: /   / 2004   Date: /   / 2004
          (Supervisor)   (Supervisor)

        Approved by the Council of the College of Science.

                         Signature:
                         Name*: **Dr.Auda Mise'l Yasir**
                         (Dean of the College of Science)
                         Date: /   / 2004

1.1 Introduction

The laser has become synonymous with accuracy and high precision in metrology and process technology. In CD players and CD-ROM drivers, laser beam is used to scan the data carrier. At increased energy densities, laser technology also provides fascinating new capabilities in manufacturing. Its possible uses are for example, in soldering, hardening, drilling, cutting, and welding.

In many cases, the technique employed for normal welding is not suitable for very small components. Micro welding is a ready solution towards the miniaturization of device and automation process. Among the several conventional micro weldings, such as TIG (tungsten inert gas), MIG (metal inert gas), and other process, the electron beam and laser beam offer an excellent role. Table (1.1) shows the comparison to competitive process [1]. From table (1.1), we can see that electron beam and laser are the two precision welding processes and they produce weld of high metallurgical quality, but electron beam cost of welding is higher than laser welding technique, because it should be carried out in a controlled atmosphere, and cannot be useful at remote areas. Laser can weld in air, vacuum, in controlled atmospheres and in pressurized chambers. In fact, laser welding produces weld of highest quality at production rates that cannot be matched by any other process. For example, laser can solder leads as soldering of 110-pin edge connectors using scanned Nd:YAG laser system. With this system, each contact can be soldered in 50 msec [2].

One of the other major benefits of laser welding is its compatibility with computer controlled processes. Because of computer-controlled power and lens, the properties of the weld will be the same one piece to

the next. Recently, robotic devices are being designed specifically for integration with lasers and will soon be operating in automated assembly lines.

Laser not only welds conductive materials but is capable of welding insulative materials such as plastic, rubber, epoxy. Early development in welding plastics with lasers showed that thin films could be joined, for example, thin polyolefin films of the order 0.1 mm thick, have been successfully welded with a Co_2 laser at speed up to 500 m/min. [3]. Since the absorption by organic polymers of IR radiation is generally very good, this fact, coupled to the relatively low melting and softening temperatures of plastics makes this type of application very attractive to the packaging industry. Refinement of this process is currently being used by Mercedes Benz to manufacture a sealed electronic Key fob.

It can be said about laser welding, that if one can see work piece, one can weld it. As progress continues in laser technology and machining techniques, process will be developed where only laser can provide the desired result.

Table (1.1) Comparison between a competitive process [1]

Characteristics	laser	E- beam	Resistance	TIG
Heat generation	low	moderate	Moderate	Very high
Weld quality	excellent	excellent	Good	Excellent
Weld speed	high	high	Moderate	Moderate
Operating costs	moderate	moderate	Moderate	Low
Tooling costs	low	high	High	Moderate
Controllability	very good	good	Low	Fair
Automation	excellent	good	Fair	Fair
Range of dissimilar materials	wide	wide	Narrow	Narrow

1.2 Thesis overview

This thesis falls in the four chapters: -

Chapter One is given to an introduction laser welding and a discussion of the interaction of laser beam with materials. The chapter also discusses the literature survey of laser welding and literature survey of control which included literature survey of stepping motor specifications, driving circuits of stepping motors, half step diving mode, computer-controlled work station, and parallel port of P.C were included in this chapter.

Chapter Two discusses the parameters of laser welding, modes of laser welding, advantages and disadvantages of laser welding, micro spot welding, and workstations of laser welding.

Chapter Three is devoted the design and implementation of hardware and software structures of the computer-controlled laser welding work station.

The last chapter includes the Conclusions obtained from this work, and the Suggestions for future works.

1.3 Interaction of laser beam with materials

High power laser radiation allows the heating, melting, vaporization, and plasma production of metallic materials. Depending on the energy distribution, it is thus possible either to weld by allowing the melt to solidify, or to cut and drill by removing the melt altogether.

1.3.1 Heating:-

When the radiation impinges on the target surface, almost all the radiation will be reflected (nearly 90%), a little will be absorbed (nearly

10%). The energy that is absorbed begins to heat the surface metal according to the followed equation [4].

$$T_s = T_o + [2I_o(1-R)]/K \ [(Nt)/ \pi]^{1/2} \quad …….……[1.1]$$

where: - T_s is the surface temp. (K^o),

T_o the initial temp.   (K^o),

I_o the power density (w/cm^2),

R the surface reflectivity,

K the thermal conduction (w/m.K^o),

N the thermal diffusivity   (cm^2/sec.), and

t the time of irradiate   (sec.).

Then the thermal conduction process occurs. The nature of the heating of material by laser beam depends on [5]: -

1-   type of material

2-   operating condition

3-   mode of operation

The reflectivity of metal surface is an important parameter because it defines how much of the light that falls on the surface is actually absorbed. Absorption of the incident laser light is described by Lamberts law, which is stated in the form [6,7]: -

$$I_{(x)} = I_o \ e^{-\alpha x} \quad ………….………..[1.2]$$

where: - $I_{(x)}$ is the light intensity penetration (w/cm^2),

to depth x (cm),

I_o is the incident light intensity (w/cm^2), and

α is the absorption coefficient (cm^{-1}).

For almost all metals typical values of α are in the range $(10^4\text{-}10^5)$ cm^{-1} [4].

The reflectivity of metals is a strong function of wave length according to Hugen Ruben formula [8]

$$R = 100 - 0.693\ (r/\lambda) \quad \ldots\ldots\ldots\ldots\ldots[1.3]$$

where: - r is the electric resistivity, and

      λ   the wave length.

Hugen Ruben formula is a practical equation, which is truthful to wave length rather than 5m [8]. Fig. (1.1) shows the reflectivity as a function of wavelength. These curves represent typical smooth surfaces of the metals. The exact value of reflectivity is a function of variable conditions including surface finish and state of oxidation of the surface. Thus, the values in Fig. (1.1) cannot be interpreted as being exact values for a specific metal. The figure does show several important general features. A metal such as gold has reflectivity that is low in the blue portion of the visible spectrum and that increases at the red end of the spectrum. This accounts for the color of gold metal. Metals such as aluminum and silver have high reflectivity that is fairly uniform through the visible spectrum. Ferrous material (steel and nickel alloys) have typically lower reflectivity throughout the entire spectrum. Thus, they usually appear more dull than metals such as silver. This is represented by the curve for carbon steel [6].

The reflectivity problem can be overcome by coating the surface with matt covering. Gagliano (1969$_s$) demonstrated that the reflectivity of polished copper at 694.3 mm could be reduced from 95% to less than 20% by oxidizing the surface [7]. As the temperature rises, the reflectivity gradually falls so that the heating rate tends to accelerate, and

the temperature rises as a function of time and the power density. Fig. (1.2) represented   absorption and heating process. This Fig. indicates absorption of the incident laser light according to he exponential absorption low in eq. (1.2); for the purpose of this Fig., we neglect the fraction of the light that is reflected [6].
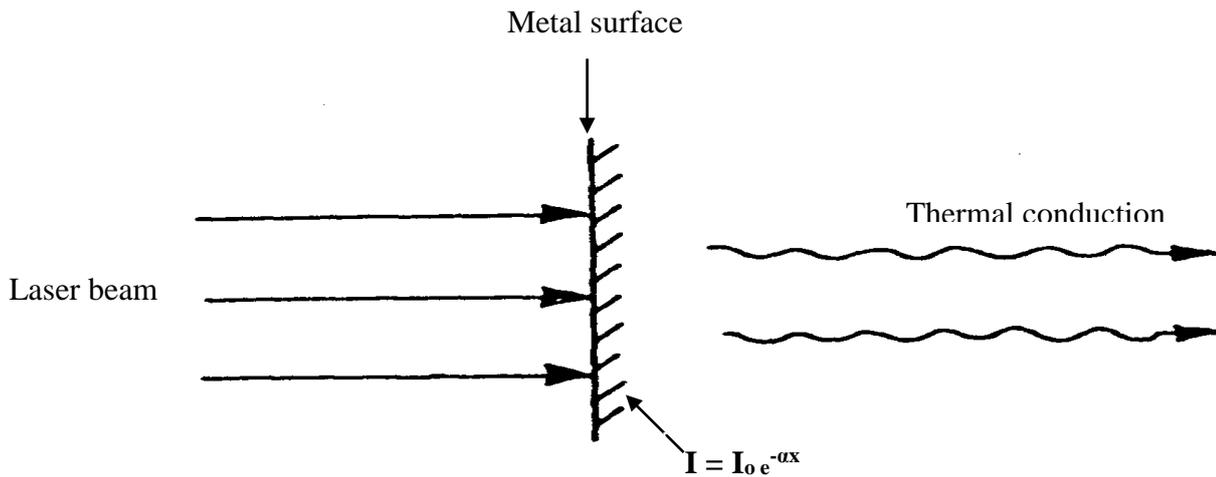
Fig. (1.2) Absorption and heating by laser [6]

1.3.2 Melting:-

With continued long and sufficient irradiation (10^5 w/cm^2), the surface temperature of target reaches the melting temperature, and the surface melting begins. This occurs at a time given by [4]

$$t_m = [(\pi K^2)/4N I_o] / [(T_m - T_o) / (1 - R)]^2 \quad \ldots\ldots\ldots[1.4]$$

Where: - T_m is the melting temperature.

When melting begins, the material begins absorb the latent heat of fusion and a molten liquid-solid interface propagates into the material and the reflectivity drops from over 90% to about 50% for common metals therefore, a molten surface interact with laser light much like a solid one [9].

The depth of penetration of heat energy in a time (t) is approximately [4,6]: -

$$D = (4 N t)^{1/2} \quad \ldots\ldots\ldots\ldots\ldots\ldots[1.5]$$

Materials differ widely in their maximum achievable melt depths, primarily due to differences in thermal properties where, thermal

properties are dependent on thermal diffusivity which is inversely proportional to the specific heat per unit volume.

$$N = K / \rho c \quad ....[1.6]$$

where: - ρ is the material density (g/cm^3), and

c is the specific heat of material (J/mol. K$^\circ$).

Table (1.2) gives the values of thermal diffusivity for several metals and alloys [10].

For effective melting, the pulse could be approximately equal to the thermal time constant for the given metallic specimen.

$$t_{const.} = x^2/4N \quad ....[1.7]$$

where: - $t_{const.}$ is the thermal time constant.

Also, effective melting with lasers depends on the propagation of fusion front through the sample during the time of interaction. Fig. (1.3) represents melted depths in stainless steel metal as a function of time for several different absorbed laser power densities. Good fusion can be achieved over a range of pulse lengths if the laser output energy is carefully controlled. For pulse lengths shorter than (1 msec), surface vaporization cannot easily avoided [6]. Melting process by laser beam is shown in Fig. (1.4) [6].
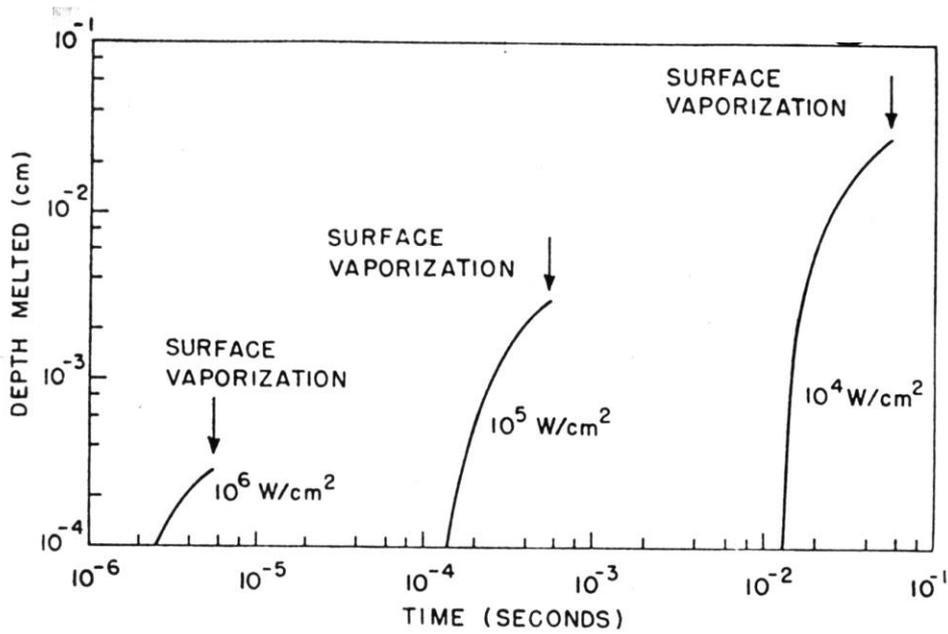
Fig. (1.3) Calculated depth melted in stainless steel as a function of time for several different absorbed laser power densities. The point at which surface vaporization begins is indicated for each curve [6]
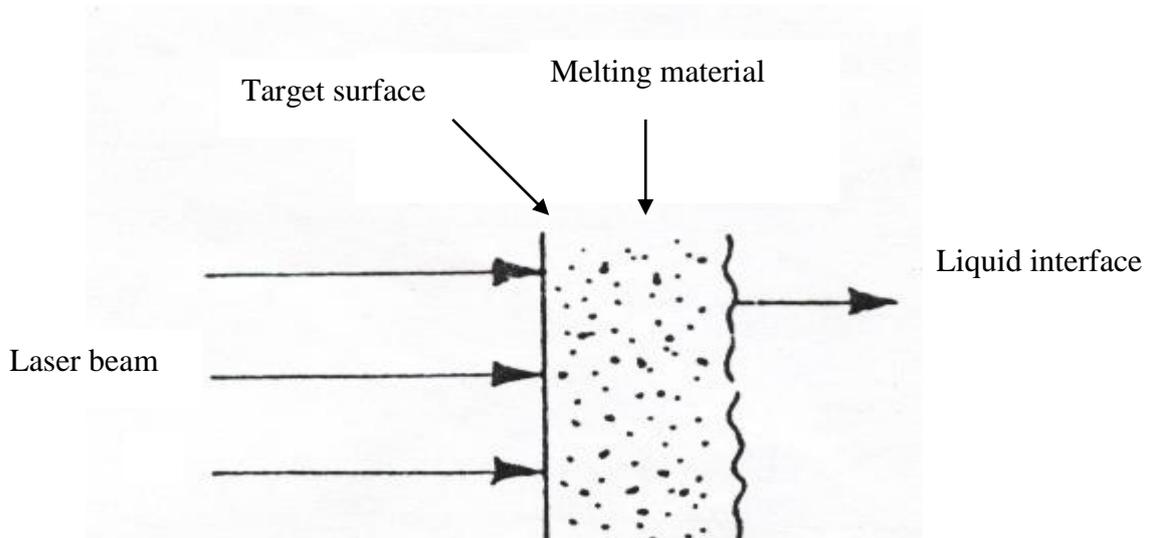
Fig. (1.4) Melting process by laser beam [6]

Table (1.2) Thermal diffusivity for several metals and alloys [10]

Material Metals (commercially pure)	Thermal diffusivity $k(*10.4\ M^2/S)$	Material alloys	Thermal diffusivity $k(*10.4\ m^2/s)$
Aluminum	0.91	Brass(70:30)	0.38
Beryllium	0.42	Phosphor bronze(5% Sn)	0.21
Chromium	0.2		
Copper	1.14	Cupro nickel(30% Ni)	0.087
Gold	1.18		
Iron	0.21	Beryllium copper(2% Be, Y phase)	0.29
Molybdenum	0.51		
Nickel	0.24		
Palladium	0.24	Inconel(76% Ni, 16% Cr, 8% Fe)	0.039
Platinum	0.24		
Silicon	0.53		
Silver	1.71		
Tantalum	0.23	6061,0 temper aluminum alloy (1% Mg, 0.6% Si, 0.25% Cu, 0.25% Cr)	0.64
Tin	0.38		
Titanium	0.082		
Tungsten	0.62	304 type stainless steel (19% Cr, 10% Ni)	0.41
Zinc	0.41		

1.3.3 Vaporization:-

After the surface reaches its melting temperature, the laser continues to deliver more energy (10^6-10^7 w/cm^2), the surface quickly reaches its boiling temperature. The time to reach boiling temperature is given by followed equation [6]: -

$$t_B = (\pi/4) \, (Kc \, \rho/F^2) \, (T_B - T_o) \quad \text{…..………..[1.8]}$$

where: - t_B is the time to reach boiling temperature (Sec.), and

T_B the boiling temperature (K^o).

Table (1.3) shows values calculated using the above equation for absorbed laser power densities of (10^5-10^7) W/cm^2 [6].

Table (1.3) Time to reach vaporization temperature [6]

metal	Absorbed power density (W/cm^2)		
	10^5	10^6	10^7
lead	118 μsec.	1.18 μsec.	12 nsec.
zinc	128 μsec.	1.28 μsec.	13 nsec.
Magnesium	245 μsec.	2.45 μsec.	24.5 nsec.
Titanium	319 μsec.	3.19 μsec.	31.9 nsec.
Chromium	1.54 msec.	15.4 μsec.	154 nsec.
Nickel	1.84 msec.	18.4 μsec.	184 nsec.
iron	1.86 msec.	18.6 μsec.	186 nsec.
Aluminum	3.67 mesc.	3.67 μsec.	367 nsec.
Molybdenum	5.56 msec.	55.6 μsec.	556 nsec.
Copper	8.26 msec.	82.6 μsec.	826 nsec.
Tungsten	10.46 msec.	104.6 μsec.	1046 nsec.

At this time, the material begins to absorb the latent heat of vaporization and a crater begins to penetrate into the surface.

At reasonable laser fluxes, the vaporized material is removed by convection and does not interact with the incoming laser radiation. When a hole begins to produce in the metallic target, the vapor builds up a pressure that causes a flow toward the exist a perture of the crater. This flushing process removes some of the mass as unvaporized droplets of the material. The velocity of the retreating surface will be approximately [4]

$$V = F_o \, (1\text{-}R)/L_v \, \rho \quad \ldots\ldots\ldots\ldots\ldots[1.9]$$

where: - V is the velocity of the retreating surface, and

L_v the latent heat of vaporization (K°).

For the general case, maximum penetration occurs, when the surface temperature has reached the boiling point.

The principal factors that govern the rates of vaporization of different elements are the temperature distribution at the surface of the molten pool and the composition of the melt. Vaporization process by laser beam is depicted in Fig. (1.5) [6].
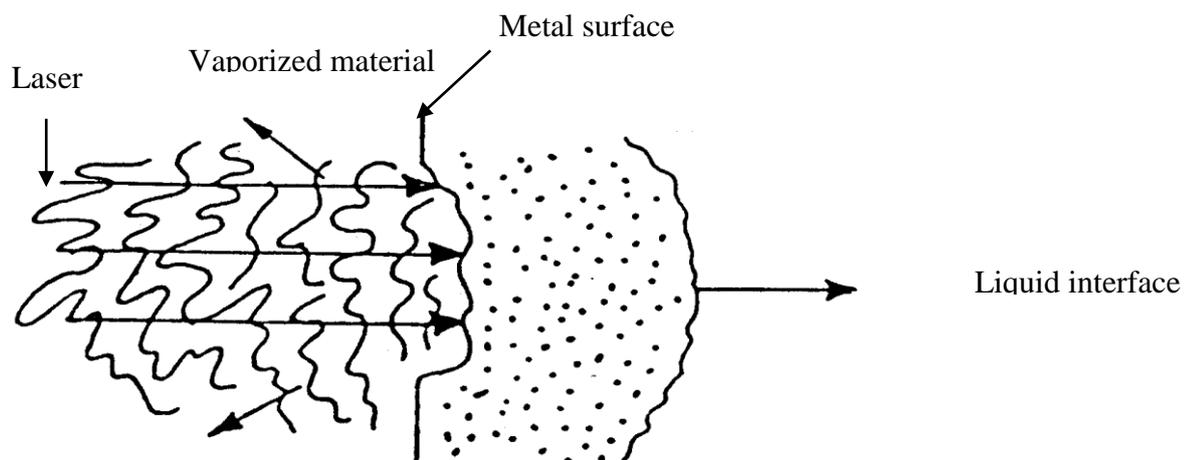
1.3.4 Plasma formation:-

Fig. (1.5) Vaporization process [6]

If the laser light is too intense (10^9 w/cm^2), the blow off material absorbs some of the incident light. The blow off material is slightly thermally ionized and produces a high temperature plasma which is formed near the irradiate surface and propagates back toward the laser, along the direction of the beam. This phenomenon leads to the so-called laser -supported absorption (LSA) wave. (LSA) wave initiation has a definite threshold value of laser power density.

Below the threshold, there is a little noticeable effect. Here, the role of the plasma is two - fold to heat up the metal surface, which is in thermal contact with plasma, and to convert laser radiation to the shorter wavelengths. Slightly above the threshold, the effect is pronounced, and is characterized by a sharp noise and bright flash of light. i.e. below the threshold, the laser light energy goes into changing the target, whereas above the threshold the energy goes mainly into the (LSA) wave or into plasma effect.

At high values of power density (between 10^9 and 10^{12} w/cm^2), the physical mechanics are approximately dominated by a process called inverse Bremsstrahlung. If the power density is increased to high values (>10^{13} w/cm^2), other physical effects become operative, which is known as a collective effect, Fig. (1.6) depicts the two processes [6].

Because the hot ionized gas (plasma) is opaque, it blocks the laser light from reaching the surface. Fig. (1.7) represents the effect of the shielding by plasma, which shows relative a mounts of material removal from an alumina target by a Co2 laser with a 1- μsec pulse duration the specific mass removal rate is a mount of material removed per unit incident energy. It gives a measure of the efficiency of the utilization of the incident energy for material removal.[6].

INVERSE BREMSSTRAHLUNG

ION RECOIL

To overcome this problem, an inert gas is used to move the plasma away from the target and to protect the optics from fumes and possible work piece spatter. The most frequently used cover gases are N_2, He, and Ar. Nitrogen is better suited for dispersing the plasma because of its higher molecular mass. Helium has much higher thermal conductivity than either Ar or N2. Argon provides better shield than helium, but is ionize easily and has much lower thermal conductivity than helium [11]. Fig. (1.8) represents plasma formation process by laser beam [6].

INVERSE BREMSSTRAHLUNG

ION RECOIL

PHOTON

FREE ELECTRON

(a)

COLLECTIVE EFFECTS

ION WAVE OR
PLASMA WAVE

PHOTON

ELECTROMAGNETIC
WAVE

(b)
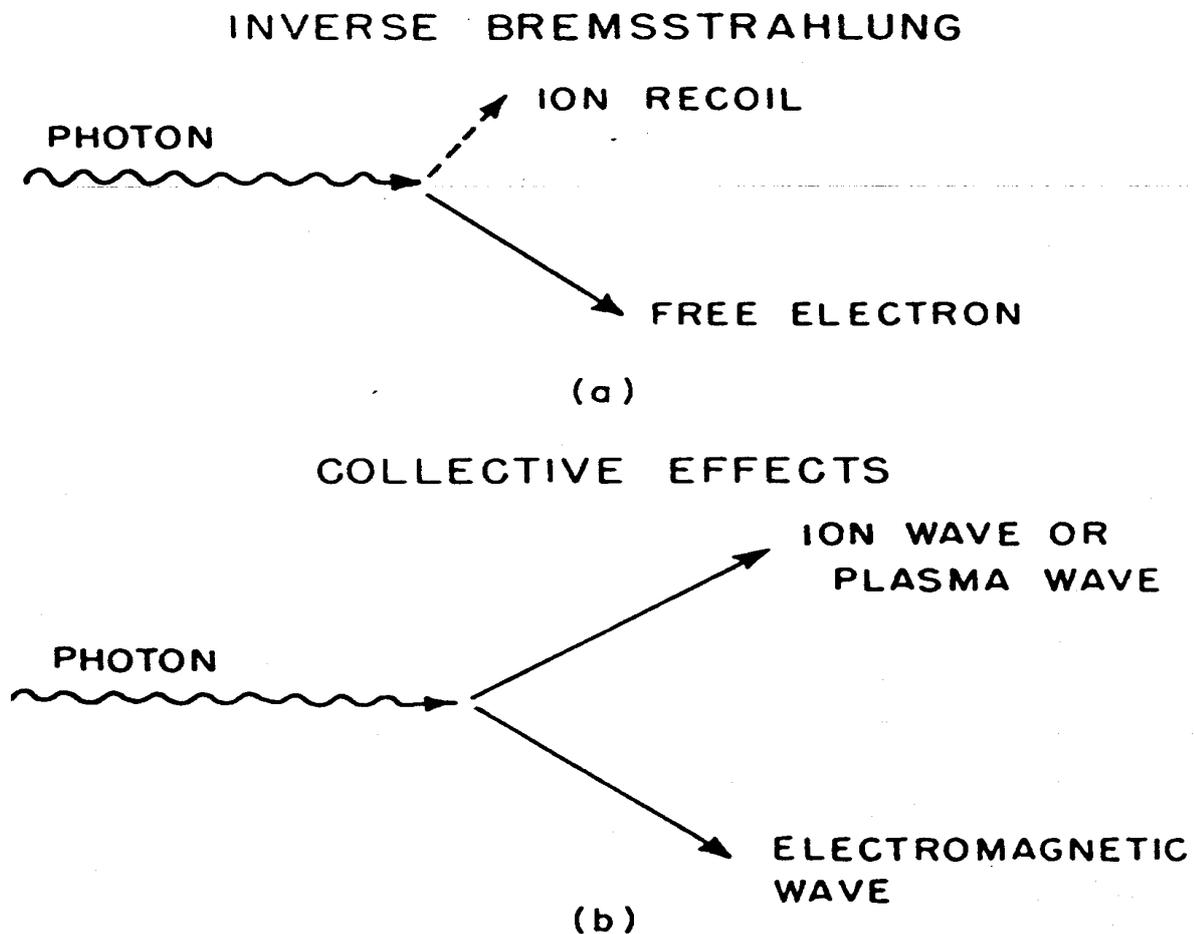
Fig. (1.7) Effect of shielding by plasma [6]
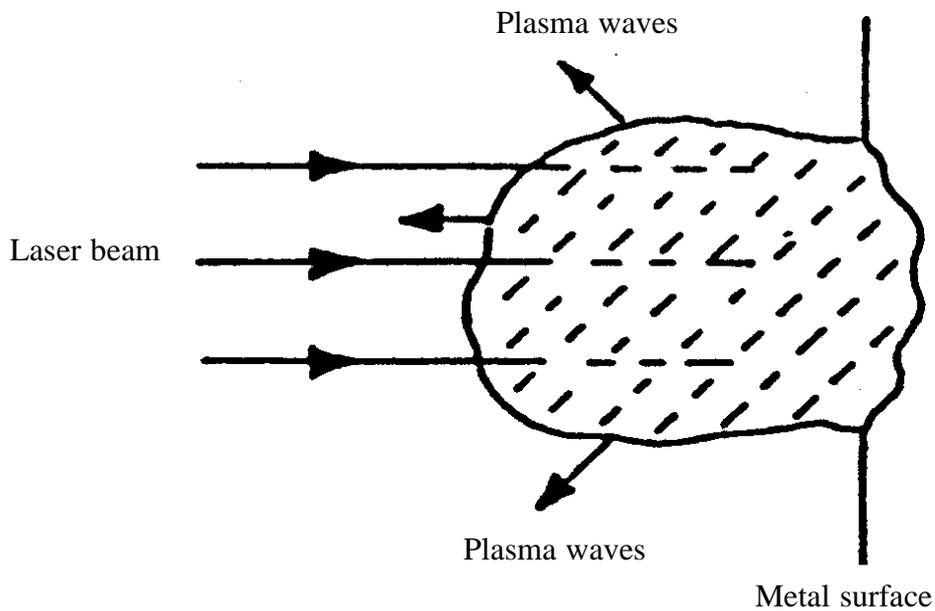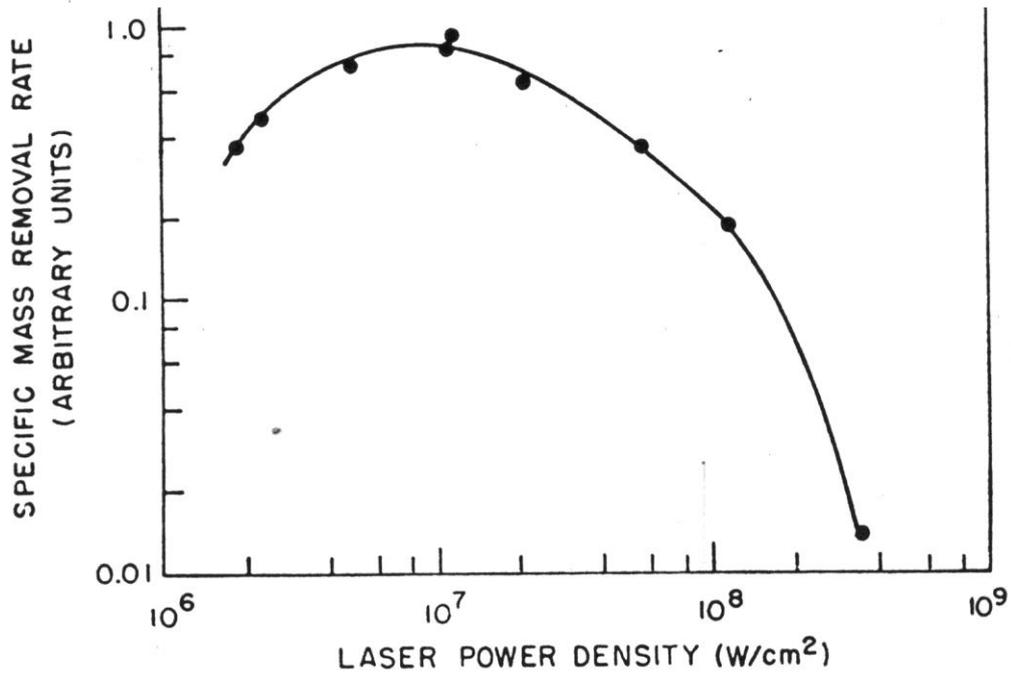
Fig. (1.8) Plasma formation process by laser beam [6]

1.4 Literature survey

The literature survey can be divided into two parts: - survey of laser spot-welding and survey of system design.

Many properties of the laser that must be properly chosen to fit into a system were presented by Gohn Ready [6] and AL- Ahmedy [12].

Many conditions that should be followed to obtain good results in spot welding process were discussed by Rykalin [13].

A spot welding for tungsten, aluminum, and platinum wires practical implementation was presented by AL- Qaisy [14]. In this study, two aluminum wires with a (0.6 mm) diameter has been welded with a (24.5 J), two tungsten wires of a (0.35 mm) diameter was welded with a (21.75 J), and two platinum wires of a (0.4 mm) diameter welded with (4.73 J). Each of the above processes has been helded by a pulse Nd:YAG laser within (10 msec) pulse width.

Gohn Ready [6] reported welding of the nickel tab to nickel alloy post used in manufacture of transistor devices. The tab is approximately (0.13 mm) thick. And the post about (0.45 mm) in diameter. A laser beam having an energy of (7.5 J) and a (3 ms) pulse length was focused with a (25 mm) focal – length lens onto the edge of the post in line with its longitudinal axis.

Debanada Missra [15] presented micro welding of thin sheets of stainless steel practical implementation. In this work, the sheets are of (0.1 mm, 0.2 mm, and 0.05 mm) of thickness. The range of pulse width, where possible welding have been achieved, is from (0.5 ms) to (3 ms) and the pulse energy ranges from (0.31 J) to (1.62 J) for thickness (0.2 mm) and from (0.09 J) to (0.51 J) for the sheet thickness (0.1 mm).

Carnely[16], Kenjo [17], and AL- Ebady [18] discussed types of stepping motors ,and   driving circuits specifications for each type. A comparison between types of stepping motors has also been presented by Carnely and AL- Ebady, many problems of driving were discussed and solved by Kenjo and AL- Ebady.

Simon [19] states the number of pulses that determine the total movement of stepping motor, and the pulse repetition frequency determines the velocity of stepping motor.

Starting/stopping control form specifications were presented by Lawrenson [20]. This paper mentioned that the total number of pulses taken by the motor were equal the total number of pulses supplied to the drive.

Miyamoto and Goeldel [21] described the single- phase excitation and two- phase excitation modes of stepping motor. Also, this paper describe an open – loop control of a single – stack VR (variable reluctance) step motor a given and constant load. All experiments were carried out with out load where the motor was driven in the single phase mode diode zener suppression circuit with a total resistance of (15.7 Ω) per phase.

P. Hill [22] described a half step driving mode specifications and gave the signal sequencing for energizing four phase stepping motor operated in half- step mode.

A   computer   controlled   dual   stepping   motors   practical implementation is given by using the computer parallel port as I/0 interface is given by Hussen [23]. Two different drive circuit for two types of stepping motors has been carried – out. Also, several chips (I.C)

has been presented to build – up the interfacing card and many flowcharts are presented to define the software program used I control process.

A robotic arm was designed by AL- Ga'y [24]. This system was build around three stepping motors that move the arm in r, ρ, and θ directions which are controlled by P.C via its parallel port.

Saeid [25] develop a flexible, modular, and cost effective P.C – Based CNC (computerized numerical control) machine controller. The designed software is capable of accepting and interapting the standard CNC (Gray code) programs. System performance has been valuated by applying the developed software to control an x-y recorder, simulating a CNC machine. The recording area of the x-y recorder is (38 * 25 cm) and the BLU (basic length unit) is (0.9412 mm/pulse). Also, the P.C operation in open loop and closed loop systems were discussed in details.

AL-Azawey [26] implemented a computer controlled laser cutting machine. This machine comprises an (x-y) table moved by two stepping motors with a maximum speed is (2 mm/sec.) and with accuracy is (± 0.1 cm), and a shutter of laser machine which are controlled by parallel port of P.C type XT which have (8088 CPU). Also, a software program used was programmed in Qbasic language which is dependent Interpolation mode. Moreover, several chip (I.C) and transistors used was discussed in details in implementation of interfacing card circuit.

The block diagram of a parallel printer interface was presented by Trible[27]. This study classified the types of printer interface into three types: data, control, and status and showed character data are latched at the outputs of the parallel interface and are carried to the data of inputs of the printer over data lines D_0 through D_7.

A references [28] and [29] were used to design a software program. These references included identification of the specific commands and

statements of a C++ language which make the user to build its software program. Also, reference [28] included the ASCII code of each key in the keyboard of P.C.

1.5 Work objective

The main objective of the work is the design and implementation of a computer-controlled laser welding work station to weld the components by the rectilinear movement of worktable (x-y) which is ideal for an extremely small parts in which handling is critical and weld size is minimal.

This work piece satisfies two features: - first welding of components manually by the keyboard, and second, welding of components locally.

1.6 Work plan

The work is divided into a number of activities are as follows: -

Literature survey of laser welding, computer-controlled work station design, stepping motor specifications, and driving of stepping motor circuit.

Specification, selection, design, and implementation of the hardware and software components of a computer-controlled laser welding work station.

Integration and testing of the overall hardware and software components of the control.

2.1 Welding by laser

The welding process involves the melting of the edges of separate pieces of material so that they fuse together to form a continuos solid structure on cooling. To form a laser weld, the laser beam is brought to focus (the beam is focused using a lens to increase the power density to a value where it is capable of melting the material) on or very near the surface of the workpiece to be joined. The first stage of the formation of a laser weld is absorption of laser light at the surface of the work piece: - high reflectivity of the metal surface can influence the result of a laser welding operation. The energy that is absorbed begins to melt the surface. Once molten, the materials are allowed to alloy and the resolidity in a controlled atmosphere, when the beam is shut off or travels away from the heated area, the molten material solidifies.

An important consideration in laser welding is that sufficient power must be supplied to melt the material but not to vaporize [30,31]. In fact, laser welding represents a delicate balance between heating and cooling with a spatially localized volume overlapping two or more solids such that liquid pool is formed and remains stable under solidification.

Such process produces three distinct regions (See Fig. 2.1) [9], the base metal, which is the material that has not been altered by the welding process, the fusion zone, composed of material that was melted during welding, and the HAZ, composed of base metal that has been changed in some measurable way by associated with welding.
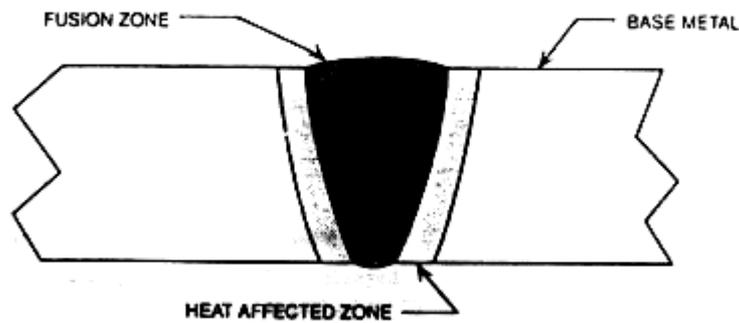
Fig.(2.1) Elements of fusion weld [9]

The parameters of the laser beam and the properties of the workpiece both influence the results of a laser welding .The most important parameter in the laser welding is the power per unit area delivered to the surface. This is determined both by the laser output and by focusing, also a good weld is obtained by positioning the focal point below the surface of the material concerned and the beam should be delivered approximately equally to each piece [6,32]. The thermal diffusivity and the reflectivity of the workpiece are important, too. High thermal diffusivity allows greater conduction of the heat and in general, permits greater depth of welding. Welding in high reflectivity metals does require some that more energy than is low reflectivity metals. Welding is more difficult with materials such as chromium and tantaluim whose melting and boiling points are close together. With these metals careful control of beam power is necessary to make good welds. Materials such as gold, copper and nickel have welding separated melting and boiling are hence easier to weld. Table (2.1) gives the general guide to numerous engineering materials which can be laser welded [33]. Generally, the most suitable metals for laser welding are those which have the same over - lapping temperature ranges and are soluble in one another. Pure metals, which have one definite melting temperature can

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usually be readily fusion welded to themselves, but not always to a different pure metal [30,33]. Table (2.2) shows fusion weldability of pure metal combination [33].

The ratio of a laser weld depth to its width depends on many variables including beam quality, power density, travel speed, material type, spot size and material thickness [9]. Fig (2.2) gives melted penetration as a function of power of stainless steel. The value of the desired energy to held welding process is detected relative to the used metal type and its depth[34]. Now, thousands of lasers are used every day to join metalic parts ranging from microscopic electronic components to heavy – gauge pipe, weld penetration range from (0.1-8) mm or more.

Weld efficiency is defined as the ratio of the energy used to melt material to the total energy input .The total weld efficiency is [11,35]:-

$$\eta_q = \eta_A \, \eta_m \qquad \text{...............}[2.1]$$

where: - η_A is the absorption efficiency, which is depending on material

and surface properties.

η_m the melting efficiency , where

$$\eta_m = m \, C \, T_m \, / \, P \qquad \text{.................}[2.2]$$

where: - m is the mass of the total melting material (gm), and

P the energy of laser beam (J).

Fig (2.3) shows the laser weld efficiency for several materials. The melting efficiency is computed from the thermal properties of material and from the section of welding area [35].

There are many properties of the laser that must be properly chosen to fit into a system. These include the following [6,12].

☐   The wave length should be absorbed well by the work piece

☐   The power level must be high enough to produce melting.

☐   The pulse duration for pulsed lasers must be long enough to permit penetration of the heat into the material.

☐   The pulse repetition rate for pulsed lasers must be high enough to weld a seam welding required.

☐   The power density and pulse duration should be chosen to fall in a regime where surface vaporization is not excessive.

In continuous welding, the speed is limited by several factors such as power density and the time for fusion penetration to the same depth. For pulsed lasers, the pulse repetition rate is a major factor too, where the welding speed increased when the pulse repetition does. For example, welding speed ranges between (0.5-5) cm/min. for overlapping spots with a pulsing rate of 1 pps, while welding with a high power CO_2 laser pulsed at (100 to 1000) HZ would give speeds of (12 to 16) cm/min. [10].

Amongst many advantages of laser welding, laser is capable of welding without filler material (autogenous welding). Autogenous welding, however, requires very tight joint fit – up which is usually a serious constraint due to the small focused laser beam size, i.e. the two pieces must be fitted closely together, in order that the material from each part can be flow and intermix. For example, if a top is to be welded to a can, the top must be held in place and two pieces together must be rotated through the beam, which is focused at the interface of the top and the can. The size of HAZ can be small if the material is thin but it is difficult to make laser welds that are narrower than the thickness of the work piece.

Filler addition, in many cases, can widen the capability of laser welding by enabling good weld quality while retaining many features of

autogenous welding. In fact there are three main reasons for using a filler material [33]: -

    ☐   To improve weld properties

    ☐   To fill gaps where acceptable joint fit - up for autogenous welding can not be achieved

    ☐   To achieve multi – pass welds and enable the laser to weld sections several times thicker than its normal single pass (Autogenous weld capability).

There are two types of filler wires and powder. The key factor in both wire and powder feed laser welding is to precisely control the relative positions of the laser beam and wire / powder feed direction in order to obtain sufficient interaction. It is more difficult to conduct laser welding with powder feed than with wire feed, because the powder can be blown away easily during delivery besides, powder usage efficiency can be low if the injection stream and the laser beam do not inter act properly .For instance, if the powder stream does not interact with the laser beam, all the powders will be wasted with out melting. Consequently the process is just like an autogenous welding. However, once the wire and beam interact in a correct position, wire usage efficiency can be 100% [36].

Really, the aim of laser welding is straightforward to use the energy in a powerful laser beam as a heat source to replace the conventional process, like MIG and TIG when this is done successfully the resultant process can exhibit an extraordinary improvement in the precision of the weld and weld productivity.
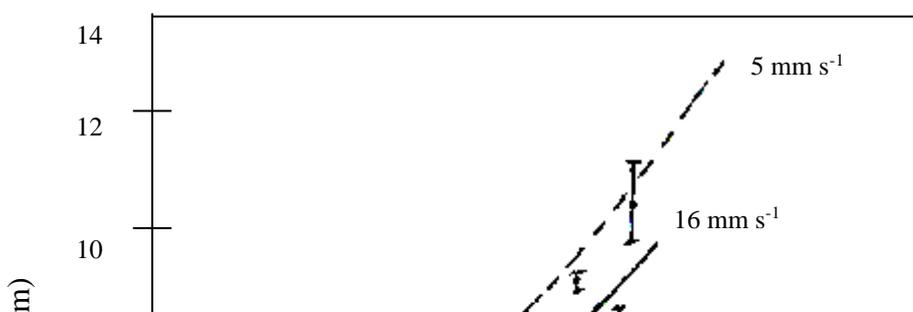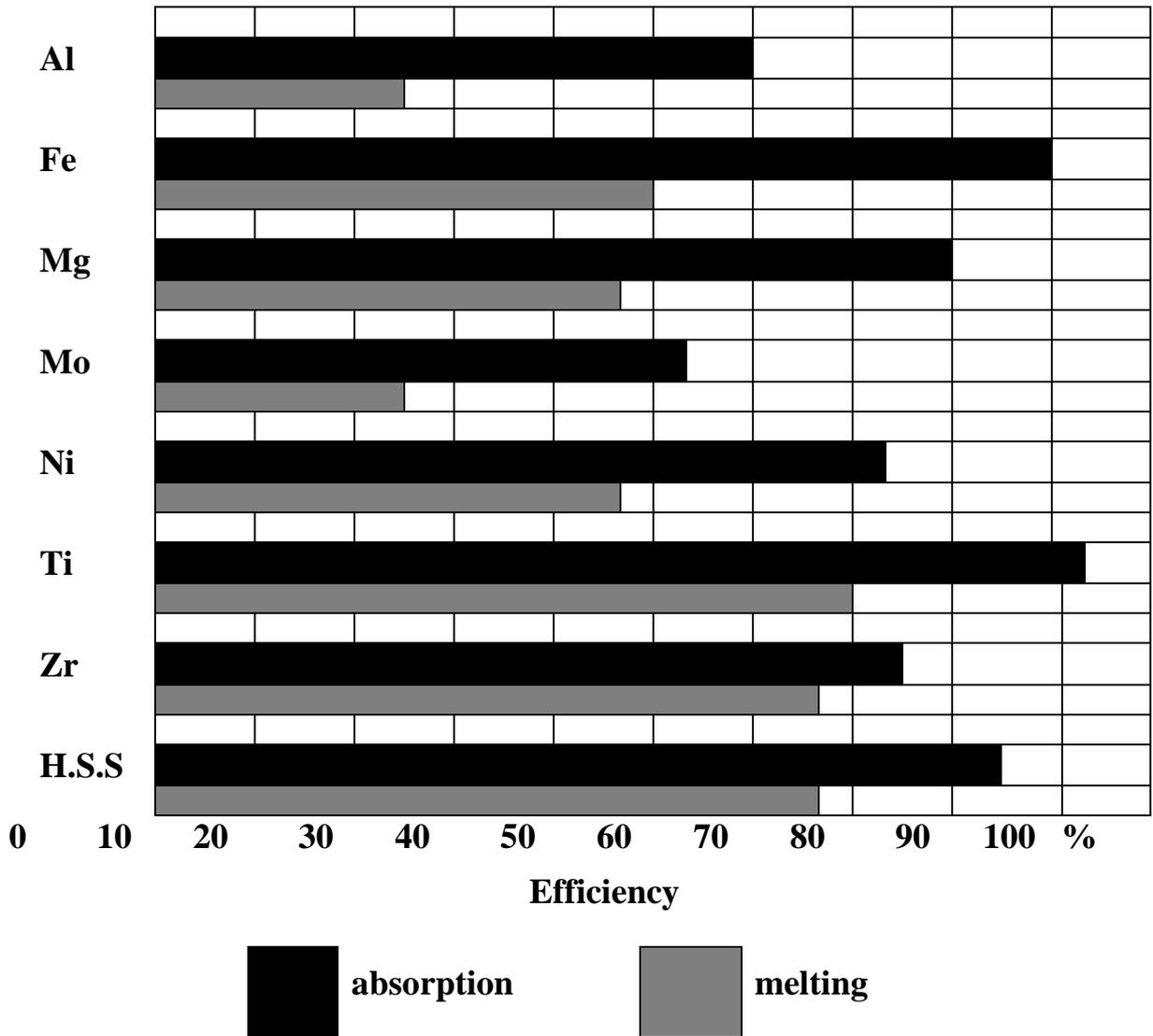
Fig. (2. 3) Laser weld efficiency for several materials [35]

Table (2.1) Guide to engineering materials, which can be laser welded [33]

Aluminum alloy	Laser welds in aluminum alloys generally have poor quality and caution is necessary for applications where high reliability is required.
copper	Only suitable for micro-spot welding application.
cast iron	Nodular cast iron can be welded using a nickel filler wire to overcome weld cracking.
Nickel base and nickel alloy	Some of these alloys weld extremely well, however, those without a number are available in different grades, which produce quite different weld qualities. There, the material manufacturer should be consulted with respect to weld properties, in case a filler material is required to improve them.
steels	Very good quality welds can be achieved provided sulphur and phosphor levels are kept low.
Medium and high carbon	Weldable, but special precautions are necessary to ensure acceptable weld properties.
alloy steels	Satisfactory laser welds have been made in numerous pipeline, shipbuilding, and structural steels. High weld hardness can be a problem due to fast cooling rate.
Stainless steels austenitic	Very good quality welds can be achieved in most grades except free machining.
ferritic	Grades with low carbon and chromium levels weld best. Weld toughness is affected by grain coarsening.
matensitic	Welds and their HAZ_s are hard and brittle due to high carbon content.
Titanium and alloy 6Al-4V-Ti	Good quality welds with fine grain structures can be achieved, but material cleaning just prior to welding and high quality weld pool gas shielding are essential.

Table (2 .2) Fusion weld ability of pure metal combination [33]

	Silver	Aluminium	Gold	Beryllium	Cobalt	Copper	Iron	Magnesium	Molybdenium	Nickel	Platinum	Rhenium	Tin	Titanium	Tantalium	Tungsten
Aluminum	B															
Gold	A	E														
Beryllium	E	B	E													
Cobalt	C	E	B	E												
Copper	B	B	A	E	B											
Iron	C	E	B	E	B	B										
Magnesium	E	B	E	E	E	E	C									
Molybdenum	C	E	B	E	E	C	B	C								
Nickel	B	E	A	E	A	A	B	E	E							
Platinum	A	E	A	E	A	A	A	E	B	A						
Rhenium	C	D	D	E	A	C	E	D	E	C	B					
Tin	B	B	E	C	E	B	E	E	C	E	E	C				
Tantalum	E	E	D	E	E	C	E	D	A	E	E	E	E			
Titanium	B	E	E	E	E	E	E	C	A	E	E	E	E	A		
Tungsten	C	E	D	E	E	C	E	C	A	E	A	E	C	A	B	
Zirconium	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E

A- Good
B- Acceptable
C- Weld with caution
D- Take extreme caution
E- Undesirable combination

2.2 Modes of laser welding

There are basically two types of laser welding:

◻ Conduction welding

◻ Penetration welding
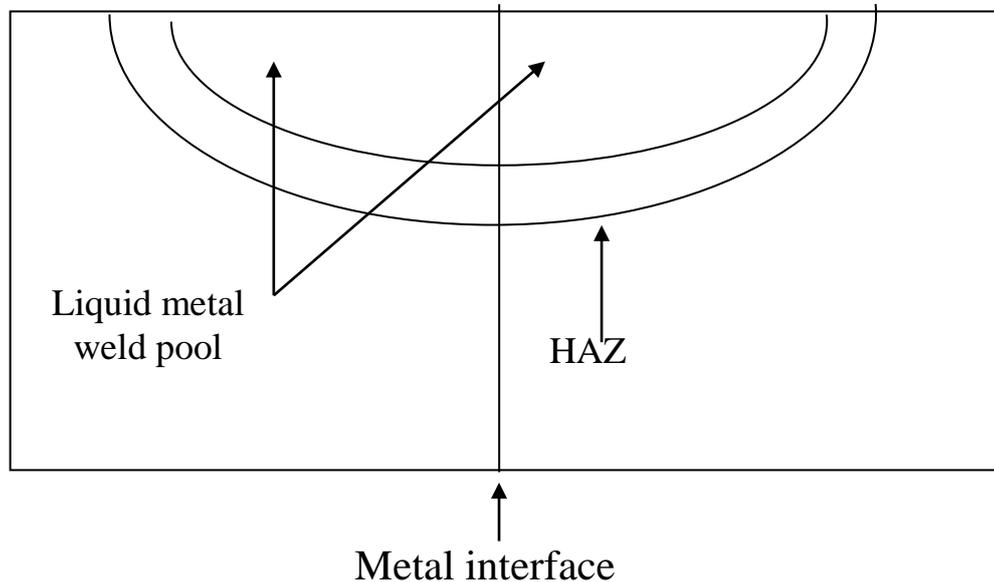
2.2.1 Conduction welding: -

One may choose to laser weld without forming a keyhole by keeping irradiance low. This process, called conduction welding, is typically done with Nd:YAG lasers rather than with CO_2 lasers. In this technique, the laser radiation does not penetrate into the material being welded, so the surface

of the weld pool remains unbroken during conduction welding process and only surface melting occurs. (See Fig. 2.4) [15].

As a result, conduction welding offers less perturbation to the system and less susceptible to gas entrapment during welding.

When there is no vapor channel, all the power is absorbed in the surface of the weld; sub surface melting occurs by conduction (hence the name of the process) and convection. Conduction welds are consequently semicircular in cross suction with aspect ratios (depth / width) of (3:1), i.e. conduction limited welds are characterized by the HAZ either side of the weld which is large compared with the actual weld depth [37,38].

Pulse and CW laser have been used for conduction limited welding in which the depth of the weld zone is limited by thermal conduction from the top surface.

Fig. (2.4) conduction welding mode [15]

2.2.2 *Penetration welding : -*

The transition from conduction mode to that in which keyhole or penetration mode is formed depends on peak laser intensity and duration of laser pulse applied to the work piece. Deep penetration laser welding was

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first absorbed when multi kilowatt continuou CO_2 lasers become available in the early 1970_s. The lower continuou laser power available previous to that time were not sufficient to initiate the deep penetration. Penetration mode allows lasers to produce welds that are deep and narrow, because power is delivered to work through the vapor channel.

The laser penetration welding technique transverse heat from the laser source into the material not to just a point on the surface, but to a line extending through the material thickness. Simply, the energy beam produced by focusing light impinges on the surface of material to be welded, causing localized heating Fig. (2.5a). First temperature is raised anti melting occurs Fig, (2.5b). A hole is then drilled into the material, and laser energy is deposited in the material through the depth of the hole. Next, this hole is transformed through the material with the molten walls sealing up behind it. By the time the metal has reached its boiling point, which may take only a small fraction of a millisecond, this raises temperature generating metal vapor. The vapor pressure created produces a depression in the melt pool which, with sufficient power, is propagated through the material being welded creating a cavity known as the keyhole Fig. (2.5c). Keyhole is a vapor filled cavity surrounded by a wall of molten metal extending the full depth of the welded. Fig (2.6) illustrates keyhole formation [39,40]. The keyhole prevents the molten walls from collapsing. Thus, much deeper penetration of the energy into the work piece is possible. When full penetration is achieved, the aspect ratio of a keyhole laser welds can be as high as (10:1) mm or more [37,38], it may be necessary to provide cover from under bead as well.

Provision of an inert cover gas is especially important for highly oxidizable materials, such as aluminum and titanium. At these high power densities all material will evaporate and give unsuccessful results. The

unsuccessful results are obtained if the melt is too large or too small or significant vaporization occurs. The quality of the weld may also be compromised by the vaporization of alloy components, excessive thermal gradient that lead to cracking on solidification and cracks instabilities in the volume and geometry of the weld pool, that can be result in porosity and void formation (See table 2-1).

If the laser is operated in a pulse energy mode, the molten metal will slump to the center of the keyhole and solidify on completion of the pulse. When the laser is operated in a continuou wave mode and the beam is moved along the joint line, the molten material at the leading edge of the keyhole produces a very small wave which is supported by surface tension.
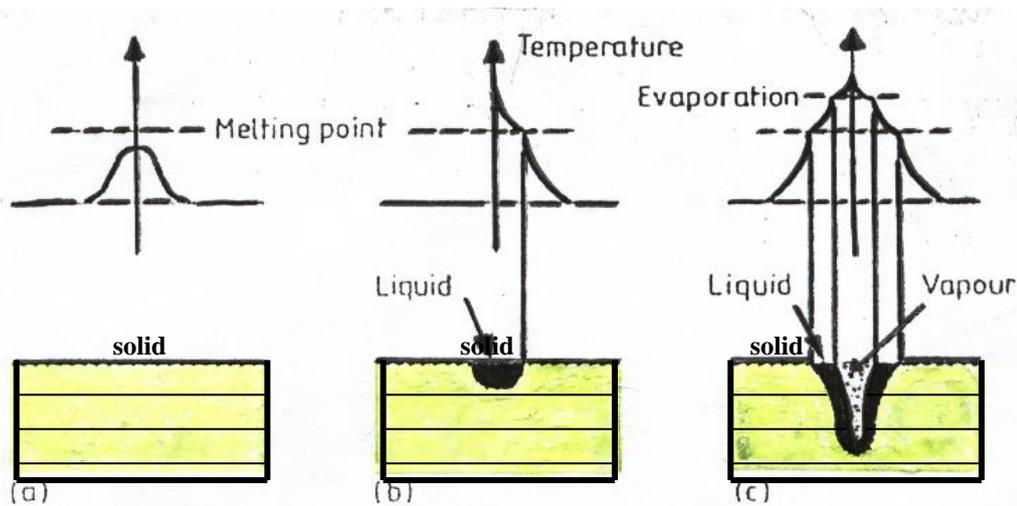
Fig. (2.5) Formation of a keyhole with increasing power density: - (a)
heating without melting; (b) melting without deep penetration
[39]
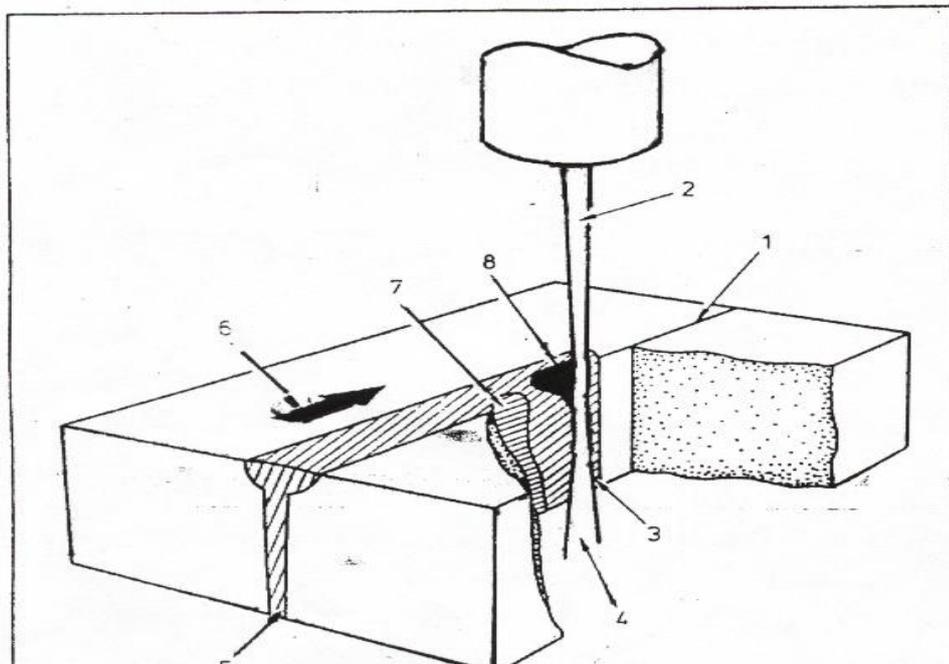
2.3 Advantages and Disadvantages of laser welding

Laser welding is one of the newest welding techniques available to industry. It is not merely an alternative technique, but a technique, which offers fabrication opportunities hitherto difficult or impossible by other welding methods. However, as have all welding techniques, laser welding has its disadvantages.

2.3.1 Advantages of laser welding [15,41]:-

1- Frequently it is faster than other technique.

2- Laser can weld exotic materials together relatively easily. This property makes laser welding ideal for hermetically sealed and other enclosed devices.

3- Beam heat input can be adjusted to near the minimum amount required to melt and fuse the weld metal, thus minimizing metallurgical effects in the HAZ (which is minimal) and distortion.

4- Because of small HAZ, laser beam weld allows heat-treated and magnetic materials to retain their properties just outside a very small and limited HAZ.

5- Laser beam can not be influenced by magnetic field of the work piece.

6- The low heat input will impose less strain on possibly brittle and sensitive materials.

7- The rapid thermal cycling of the narrow fusion zone limits grain growth during heat.

8- The materials to be welded are not electrically conducted.

9- LBW is a non-contact process, so there is no tool wear and no risk of contamination.

10-   Materials can be welded together, reducing the post weld cleanup of excess filler material.

11-   Inaccessible areas or even encapsulated materials can easily be reached with the laser beam.

12-   Easily automated process that can produce very precisely located welds.

13-   Its ability to perform its function on precisely the area alone.

2.3.2 Disadvantages of laser welding [15,41]:-

1- Surface reflectivity causes a major problem during welding.

2- The capital investment required is high compared with most techniques

3- Extremely hard weld bead in pardonable materials; cold cracking, and hot cracking may be problems due to rapid heating and cooling.

4- Production of a laser beam is less efficient than other sources such as electron beam.

5- It depends on consuming high rates of waters and gasses.

2.4 Micro spot welding

Advances in manufacturing technology the push for smaller part geometry has opened up new metals joining applications where traditional welding methods no longer meet the high precision, quality and productivity requirements. Highly localized and controlled heat generation is essential for such smaller welds. Micro spot welding in electronics industries refers to welding in very small components.

Laser spot welding has become a versatile tool for welding small components. It is particularly useful in cases where localized heating is desired, such as welding near glass –to- metal seals or inner connection of leads in delicate heat – sensitive semiconductor circuitry. The primary advantage of the laser over other welding techniques is its ability to perform its function on precisely the area alone. Many sensitive materials cannot tolerate the high temperature levels to which they are subjected during conventional welding processes .Low power laser spot welding technology is now being used for these processes. Many of the early investigations of laser welding in the 1960s emphasized spot welding, because the lasers available at the time were ruby or Nd:glass lasers with relatively low pulse repetition rates available . One investigation of laser spot welding involved the use of high repetition rate Nd:YAG laser to weld insulated copper wires to terminal posts . In this process, laser radiation was used both to remove the insulation and to produce the weld . The main problem during the micro welding arises in having a low HAZ and controllability of other parameters [6].

Many joining tasks in the production of the electronic components are preformed using spot welding for two reasons. First, the entire component usually has to be a medium strength. Second, the individual components that are to be connected only allow welding to be carried out in on area of a few hundred micrometers miniaturization. This, however,

means that very high standards are set for the welding positioning accuracy and the size of the welding spot. The aim of micro laser spot welding in electronics industries is straightforward –to use the energy in a powerful laser beam as a heat source, the power density can be reduced to produce melting with out vaporize. This case more closely resembles that of GTAW (gas tungsten arc welding), and is referred to as a conduction or melt-in mode, this mode is useful for welding thin sections. The type of welding used in packing phtonic devices falls into the category of conduction welding where relatively low power (< 50 W) Nd:YAG lasers are used[42].

A key factor whether a metal is a good candidate for laser welding is how well the heat at the weld area can be contained to allow a weld pool to form and minimize the HAZ. That parameter is the thermal diffusivity N; the smaller the N, the slower heat will be conducted away.

Another consideration is the non-metallic constituents in the metal. Good welds are achieved with low carbon steels ($< 0.3\%$ carbon); steel with higher carbon content tend to form martensites when cooled rapidly, which are prone to cracke [43].

For spot welding with melt pool diameter of (0.5 to 1 mm) the laser system delivers pulses with an energy of (1 to 5 J) and a direction of (1 to 20 ms). The short duration reduces energy leakage from the melt pool during the laser pulse, thus minimizing the HAZ [44].

The earliest studies of laser application in electronics usually involved welding of microcircuits. Ruby lasers welded a variety of electronic components. Specific items included welding of leads to circuit boards and to tabs on silicon chips, welding fine wire to thin films, and welding flat packs to circuit boards. Spot welding between a nickel tap and a nickel alloy post on transistor header has reached a routine production

status since 1978$_s$. In this instance, the packages are usually nickel-plated iron-nickel-cobalt alloys.

Electrolytic and electroless plating technique are used. Welds on electrolytic nickel-plated are prone to very fine surface cracks, which are usually very shallow. Electroless nickel plantings, however, produce serious solidification cracking when welding in a continuous wave mode. These cracks can be reduces by pulsing the laser beam and satisfactory results have bean achieved using Nd:YAG laser pulsed at 150 Hz and using 1msec. pulse lengths [33] .

Laser micro spot welding is readily compatible with present electronic packing and appears particularly applicable for beam -leaded devices. Since such leads are now attached under a micro scope, one may foresight the laser beam to the focus of the same microscope, and deliver the laser energy to center of the microscope field of view. A number of leads can be weld simultaneously to integrated circuit board. This is achieved by positioning the lead automatically and the laser pulse spreading at appropriate optics (this is discussed in paragraph 2.6) to weld all the leads for a given circuit simultaneously. In one example, a ruby laser pulse has bean spread to weld four leads with a Ti Pt layer to a thin gold film on an alumina substrate.

Gold platings are rarely used on steel but are common on the iron – nickel cobalt alloy microcircuit packages in the electronics industry. These materials laser weld extremely if a thin gold flash is used, but thick plating can cause weld solidification cracking. In all this application, the simple beam guidance used in combination with energy output can be focused onto extremely small areas in order to create electrical contacts [33].

Both pulsed and continuou – wave laser are used for micro spot welding. CW is used for speed while pulsing is used for precision. If the

work piece is thin, very high travel speeds are required to keep the heat input low if the laser is on continuously. Pulsing the beam lets more reasonable speeds be used.

Generally for spot welding a pulsed solid – state laser is used .The complete installation consists basically of a laser head and cabinet of power supply, control and cooling. Special elements are : The energy monitor, continuously indicating the energy given out by the laser ; ,the shutter, , a device to shut off , at any time , emergence of the beam ; ,the protection glass, , protecting the (expensive) focusing lens against metal vapour and possible spattering , and the microscope , used in some arrangement to locate the welding spot and to evaluate the weld.

There are five conditions that should be followed to obtain the maximum benefit in micro spot welding process [13]:

1- Accurate beam / joint alignment is necessary, the narrow weld can easily miss the joint line if accuracy positioned.

2- The depth of beam focus must be small and its position about the work surface should be maintained accurately to achieve the required power density, where the work piece should be positioned in the center of focus laser beam to prevent a varying in power density. A varying in power density to a distance (L) from the center can be evaluated by:

$$s = s_f \{ 1 \pm 2\,L / f \} \qquad \ldots\ldots\ldots\ldots\ldots[2.3]$$

where: - s is a varying in power density,

s_f the area of laser spot, and

f a focal length .

3- Precision work piece or beam manipulation equipment is necessary to control energy input if the laser out put is too low; the work piece will not be completely melted. If the laser output is too high, the surface will be partly vaporized and the strength of the weld will be reduced. Fig (2-7) shows data on the required output of a ruby laser to weld copper and nickel wires, as a function of wire diameter.

4- If is to be welded a wire to a bulk material, the melting duration of wire must be rather than bulk material.

5- A pulse duration of laser beam must be shorter than the vaporization duration of bulk material. Table (2.3) shows data on the required output of laser beam to weld tungsten and rhenium wire. In general there are three parameters that determine the outcome of micro welding applications.

In general there are three parameters that determine the outcome of a spot welding application. Laser welding systems must have provisions for varying these parameters. They are:

Spot size – Diameter of the weld beam on the metal. The optimal spot size is a balance between achieving the desired structural integrity and minimizing the HAZ. The spot size should also be smaller than the depth of the melt pool to minimize the stress on the weld surface.

Peak power – The laser power density must be sufficiently high to melt the metal, but not so high as to cause significant plasma formation.

Pulse width – The laser pulse width, measured in milliseconds, determines the amount of energy impinging on the weld bead. This parameter, together with peak power, also determines the penetration depth, which affects the geometry and strength of the weld joint [44].
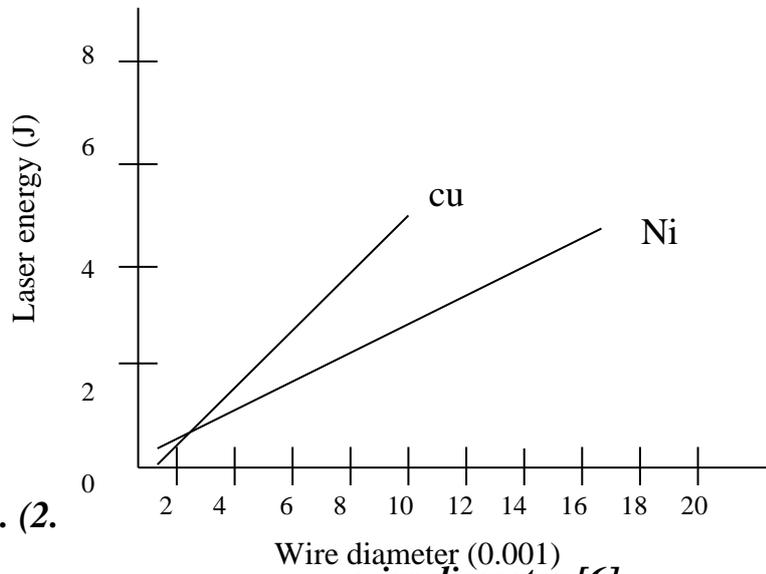
Fig. (2.   nction of
wire diameter [6].

Table (2.3) Shows data of laser beam to weld tungsten and

rhenium wires [13]

Material	Pulse energy J	Focal distance cm	Pulse duration m sec	Weld type	Diameter mm	Note
Tungsten	1.12	18.8	3	Butt	0.1	Welding in air and argon atmosphere
Rhenium	5.2	5.0	1	Parallel (over-lapped)	0.35	

2.5 Comparing CW to pulse welding

A variety of lasers are available for welding applications. These lasers are available in three modes:

☐   Continuous output.
☐   Pulsing pumping.
☐   Q – switched mode.

Q – switching of the laser is less useful in welding applications because pulse durations are much shorter (1 msec.) although the pulse repetition frequency can be high. Both pulsed and continuous lasers are more useful in welding applications. This section is intended to compare between each technique.

2.5.1 CW laser welding [11,15]:-

☐   Generally it offers welding speed.

☐   It does allow higher heat input to the part.

☐   It creates more HAZ than pulse welding.

☐   It must emit several handred watts to have comparable metal working capabilities because the high peak power in the pulse can break down the surface reflectivity.

☐   It is best choice to weld thick materials than pulse welding.

☐   It would be a better choice for seam welding.

☐   It can be used for deep penetration welding.

2.5.2 Pulsed laser welding [11,15]:-

☐   Welding speed is slower than CW.

☐   It has a smaller HAZ.

☐   This processing method adds less heat to the part.

☐   The process is good for low - power welding

☐   It can be used for pulse welding a small parts, called micro welding such as wires to terminals and electronic components.

☐   A high repetition rate more than (30) pulses per sec. Laser would a better for seam welding.

☐   The repetitively pulsed laser gives deeper penetration because of the higher peak power during the pulse.

2.6 *Work stations of Laser Welding*

The laser as industrial tool offers advantages not found in most other industrial processes as mentioned previously. The higest advantage in contemplating a system design is the ability to move either the work or the beam or to modify the beam.

Work cell stations fall into the following categories, depending upon the production requirements of the manufacturing workstation[45]:-

1.   Single axis rotation of the work.

2.   Adapted rotary and till mechanism.

3.   Multi-station dial feed index.

4.   Robotic movement of work table(x-y) and the beam z.

5.   Gantry type movement (x-y-z) travels of the beam delivery system.

6.   Robotic arm movement.

The first category of controls, and the simplest, they have the advantage of being low cost and easily maintainable. They are extremely limited in their ability to handle varying situations.

An improvement over relay sequence system is the programmable logic controllers or PCs. These were originally solid state replacements for relay logic system, and were capable of handling a variety of possible sequences. They are easily reprogrammed, as the welding machine logic is contained in software rather than in the arrangement of the hard wired

relays. The abilities of programmable controllers have also been improved so that now they can handle many tasks such as monitoring welding variables and program branching to handle variations in sequence. They can also be interfaced to higher level computer networks for functions such as maintenance and productions reporting. Recently, PCs have been become capable of doing closed loop control for a single axis of motion.

The most sophisticated level of control is the computer. This unit is characterized by its ability to do all of the things the programmable logic controllers can do, plus the ability to handle motion control of several axes in coordination. These controls are also marked by the ease with which they can be reprogrammed and the use of hugh level language. They can, therefore, handle a wide variety of parts, and the ability to write and load programs rapidly makes it possible for them to handle small lot sizes with very short set-up times [45]. However, succeful laser welding depends on the way the work is held and manipulated beneath the laser beam, or the beam manipulated about the work.

2.6.1 Work piece manipulators

Rotary work piece manipulators are the most simple and common, as the majority of mass produced laser welds are made in some form of circular butt or lap joint. Rotary manipulators are available from many welding equipment suppliers, although for laser welding the speed range may have to be increased. The latter requirement also sometimes necessitates a larger drive motor to produce the torque necessary for the component weight. For small production, a small lathe can be used to rotate the work. On the other hand, a purpose – built rotary table can usually operate with its prorating axes positioned any where between the vertical and horizontal and thus offer more flexibility to component variations and laser beam access. Care must be taken when mounting work piece requiring butt or lap joints on rotary manipulators to ensure the joint line rotates concentrically with the axes of rotation, otherwise the work surface will move in and out of the laser beam focus position as the work rotates. Also, to ensure the laser beam remains on the joint line, the line must be position sequare to the axes of rotation. To make straight welds on flat surfaces up to (1 m) long, a wide choice of commercial tables is available from numbers suppliers. Must of the tables capable of (1 m) movement operate at welding speeds up to and sometimes an access of (7 m/min.). Generally driven by DC servo ore linear motors with encoder speed control, they also have relatively high rates of acceleration and deceleration. Rotary work piece manipulation as shown in Fig. (4.8 a)

Other systems that illustrated moving the work piece might be employed on (x-y) axis table as depicted in Fig. (2.8 b). These comprise two linear tables, one mounted on top of the other. These tables are light, fast, accurate, and can be controlled by variety of input from keyboard, disks, cartridge, and PROM.

Whether the work tables are linear or x-y, they most mounted on a solid pedestal base, which can react to the combined in ratio of the moving table and work as they come to rest or change direction. Also, if the table is mounted on the milling machine bead knee, it will provide an accurate Z movement (vertical up and down) control, which will enable the focused laser beam position to be simply adjusted an accurately set in relation to the work piece surface.

The use of linear and (X-Y) table for moving large component, which invariably also require long weld lengths, can pose numerous problem. For example, the acceleration distance the table has to travel before it reaches the required welding speed, and likewise the distance for deceleration have to be add to the travel distance required for the weld length. Also, when using large linear and x-y tables, an often any unforeseen disadvantage is that they require a large floor area to allow for the table travel distance. For example, a (2*2 m), x-y table with (2 m) travel in each axis, will require a floor area of at least (16 m2), plus sufficient area for access.

In many cases, (x-y) tables are driven by stepping motors, to select the proper motor for the specific application, the following factors must be considered [46]: -

1-   number of steps per revolution
2-   moment of inertia of the load
3-   friction load (torque)
4-   maximum stepping rate

2.6.2 Laser beam manipulation

Welding in a circular pattern, standardized rotating lens or mirrors assemblies are available. These devices typically rotate a focusing mirror or lens in a horizontal plane on an axis coincident with the incoming stationary beam as shown in Fig. (2.8 c). As the focussed spot will always be on the focal axis of the lens, it will be rotated in a circle with the lens. The rotating lens assembly typically is driven by a variable-speed motor and may be equipped with an assisting gas jet.

The effective radius of operations is limited by the lenz size used. The beam might also moved in an (x-y) system utilizing an (x-y) table as illustrated before. The beam in this system can be moved by an arrangement of light weight mirrors and focusing head at speeds that are only limited by the capabilities of the (x-y) equipment.

Laser can also be split or time shared by passing moving mirrors through the beam in such away as to deflect in different directions at selected times to perform operations at sperate stations as be shown in Fig. (2.9) [33].

Laser beams may be Scanned Slowly or at extremely high rates by using mirrors which are mounted to mechanically oscillated mechanisms to electrically controlled galvanometers. In fact, If the beam movement with agalvanometer scanner, it will be offered and ideal characteristics. The speed of the beam on the component that can be achieved, the position accuracy and the spot diameter result from the focusing conditions. A standard optical system has a focal distance of 100 mm and achieves a repetive accuracy of) ± 15 μm) in positioning.

One feature that is important in laser beam welding with a galvanometer scanner is the option of carrying out a position check and, if necessary making corrections, before the welding spot are set.

Many of the electronic components that need to be connected are manufactured using mechanical separation and shaping processes. For this reason there are, for example, tolerances can account for up 30 percent of the spot diameter. By sing an observation system fitted along the course of the beam in front of the galvanometer head, in combination with an image processing system, highly precise welding spots can be set, despite tolerances that are difficult to reduce.

The simple linear movement laser gun gantry system does not necessary introduce any more beam fold mirrors into the beam transmission path than are used by a work station with a fixed laser gun.Furthermore, without introducing any more mirrors, a (Z) movement axis for the gun can be applied. Combining these two axes of gun movement with a single linear table and driving each by NC (numerical control) will provide a basic programable three axis robotic system. If two additional refilective poptics are used one of which could focus the laser beam, then 5 axis beam workpiece mainpulation can be achieved as depicted in Fig. (2.10).

Types of large gantries have to be precision made and often temperature-controlled to maintain the necessary very high accuracy of optical allignment through the beam transmission mirror train.

Multi-axis gantries operated in conjuction with Co_2 lasers, apart from being very expensive, lose a subsstantial amount of laser power during beam transmission. Each mirror in a Co_2 laser beam transmission train absorbs approximately 3 to 5% of the laser power,depending on the mirror conduction.

Laser beam (except Co_2) can be transmitted down afibre optic with no appreciable loss of power. In this optical fiber the laser beam can be transmitted over considerable distance(up to 100m) with no significant losses. This ability means that the light can travel via a filexible cable to a laser gun mounted on an articulated wrist of a robot arm, at the far end of optical fiber there is a " welding head" with a lens that focuses the beam emitted from the fiber on to the workpiece as shown in Fig. (2.11). In this techniques, laser beam can be split too, using several optical fibers as be shown in Fig. (2.12 a) [33].   The multi-mode beam from an Nd:YAG laser can be split by inserting staggered beam folding mirrors into and cross the beam path. Thus the beam splitting system, inconjuction with a fiber optic beam delivery system, can make several welds simultaneously in one or more workstations as be shown in Fig.(2.12 b) [33].More over, laser can switched from station to station. In fact, there are industrial micro spot welding system where the beam is switched among eight workstations at up 40 times per second [33].

(2.8a) Rotary System

(X-axis)   (Y-axis)
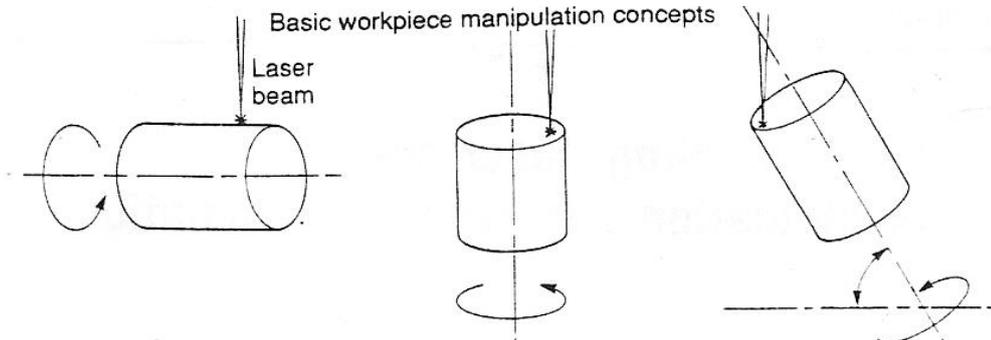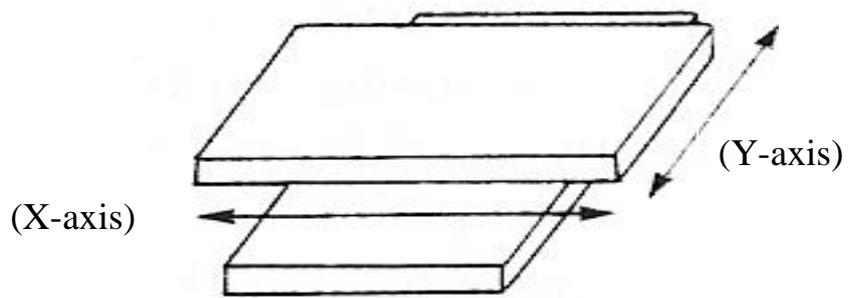
(2.8b) X-Y table
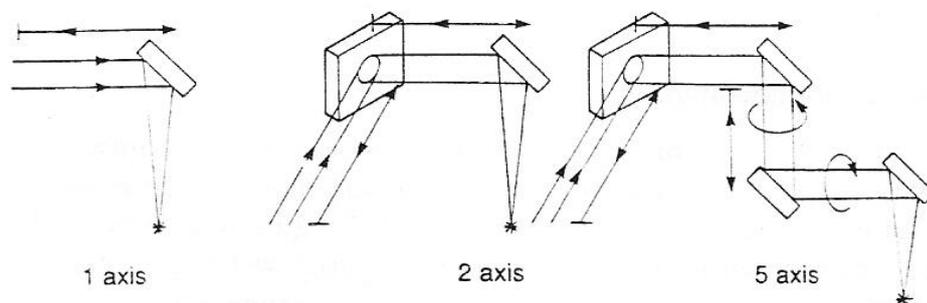
(2.8c) Rotating mirrors

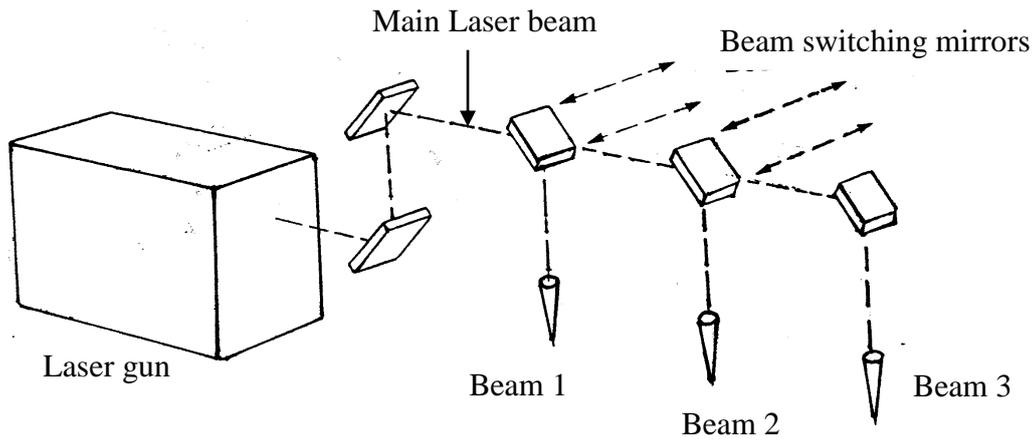***Fig. (2.8) Work piece and laser beam manipulation concepts [33]***

Fig. (2.9) Laser beam time-sharing by inserting fully reflecting mirrors sequentially into the laser beam path. [33]
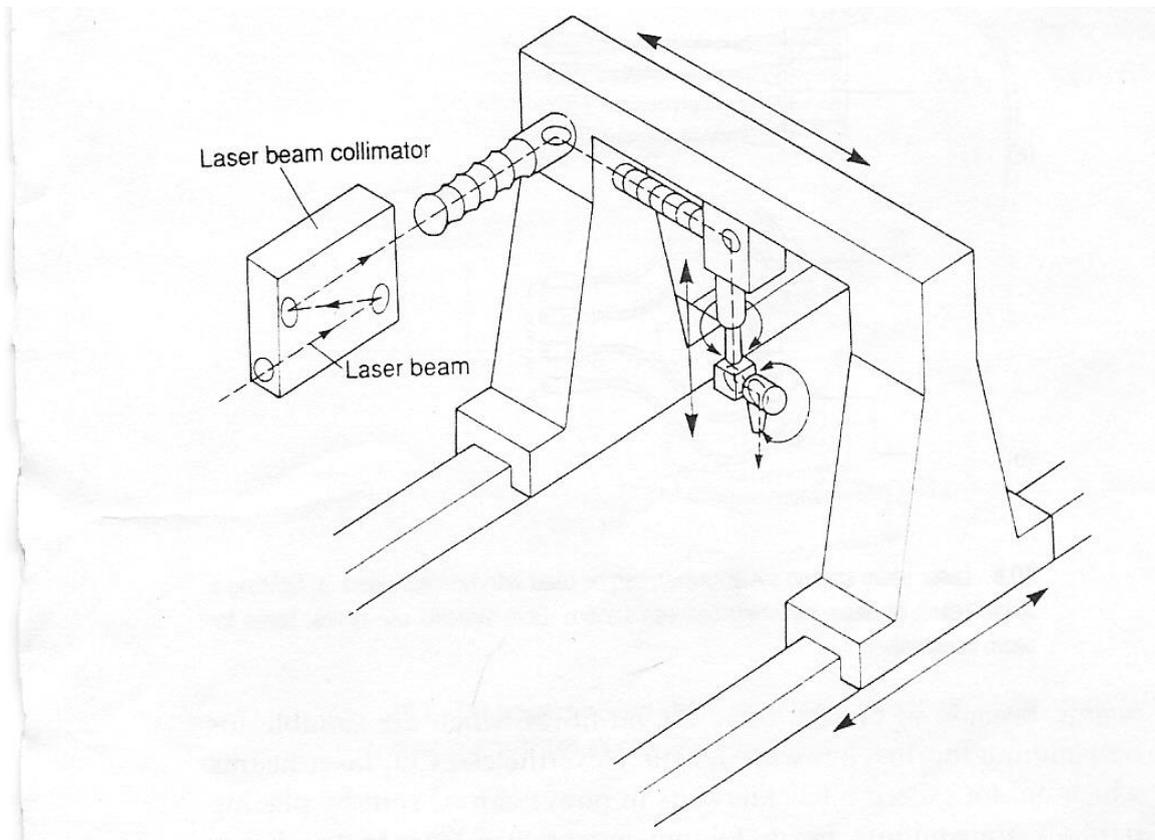

Fig. (2.10) General arrangement of a 5 axis gantry based robot for manipulating the laser gun about large stationary work piece [44]
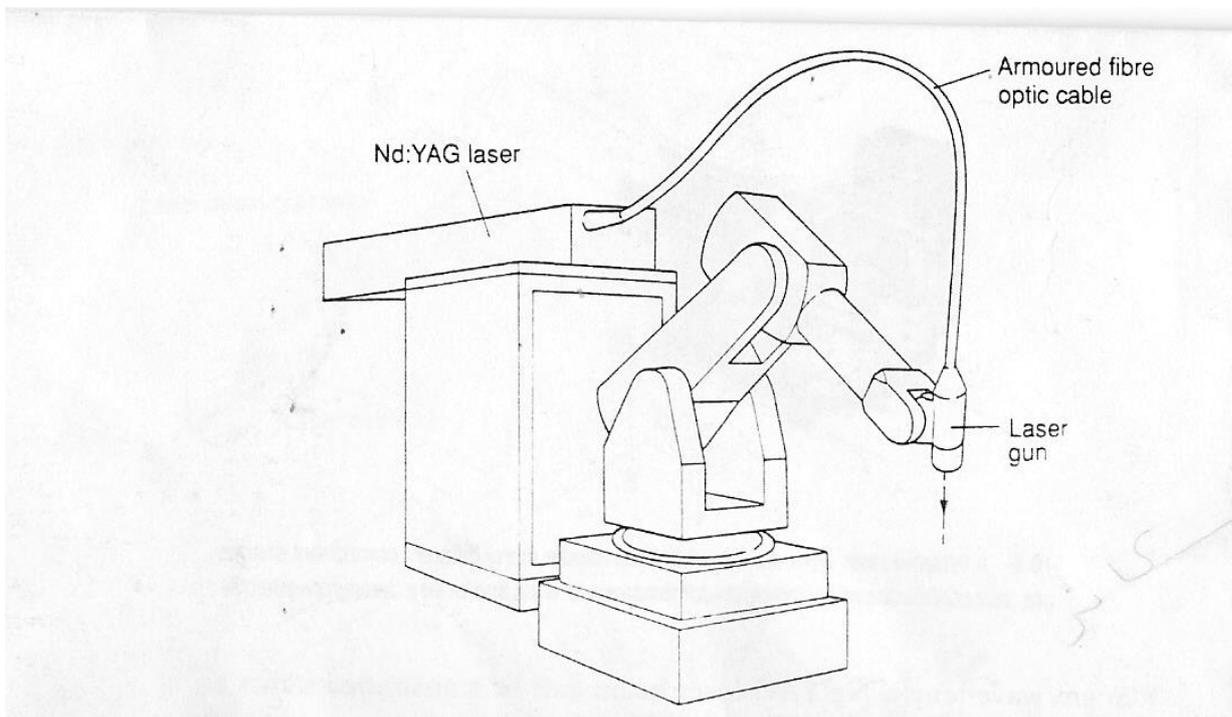
Fig. (2.11) Utilization optical fibre in robotic laser welding system [44]
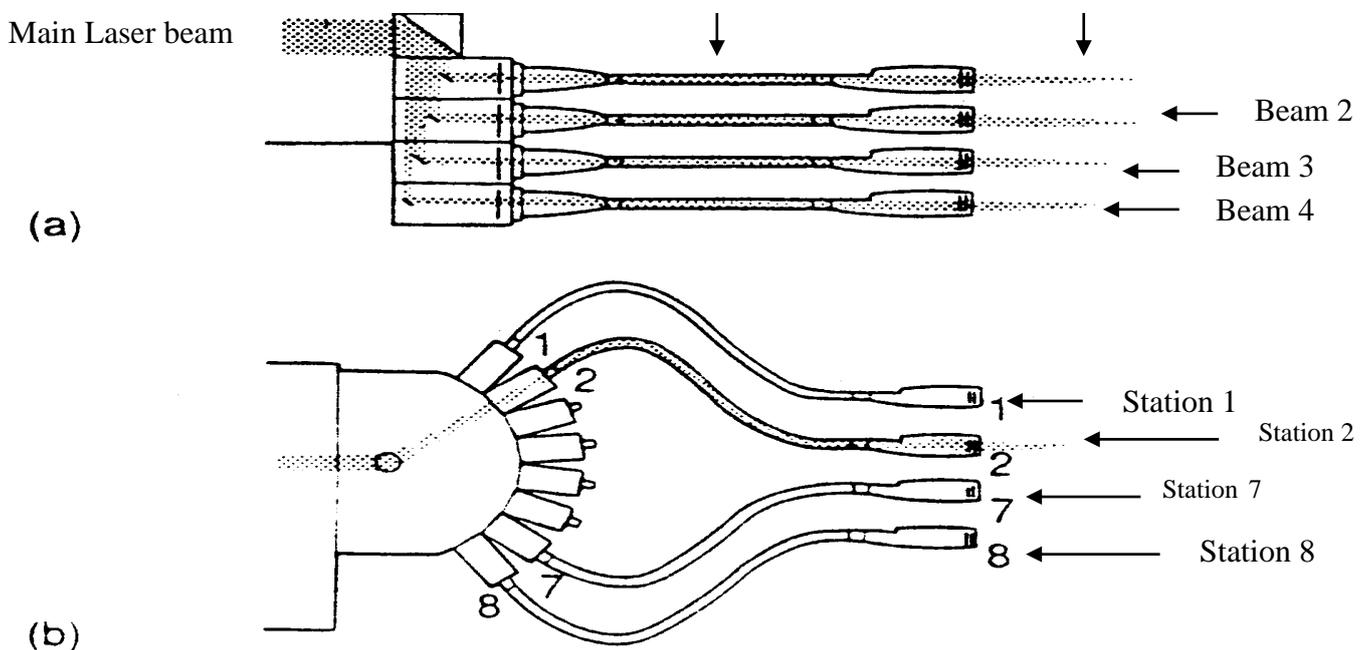
Fig. (2.12) Laser beam sharing system: - a) splitting a single beam b) beam switching between stations. Both systems use optical fibers for beam transmission. [33]

3.1 The hardware structure of the system:-

The complete system can be divided into four main parts: laser machine, PC. , interfacing card , and (X-Y) table as shown in Fig. (3.1) . Simply, a P.C has been interfaced with two stepping motors of (X-Y) table and with circuit of sequencing shutter by interfacing card will be discussed in detail. Specifications of P.C are listed in table (3.1).
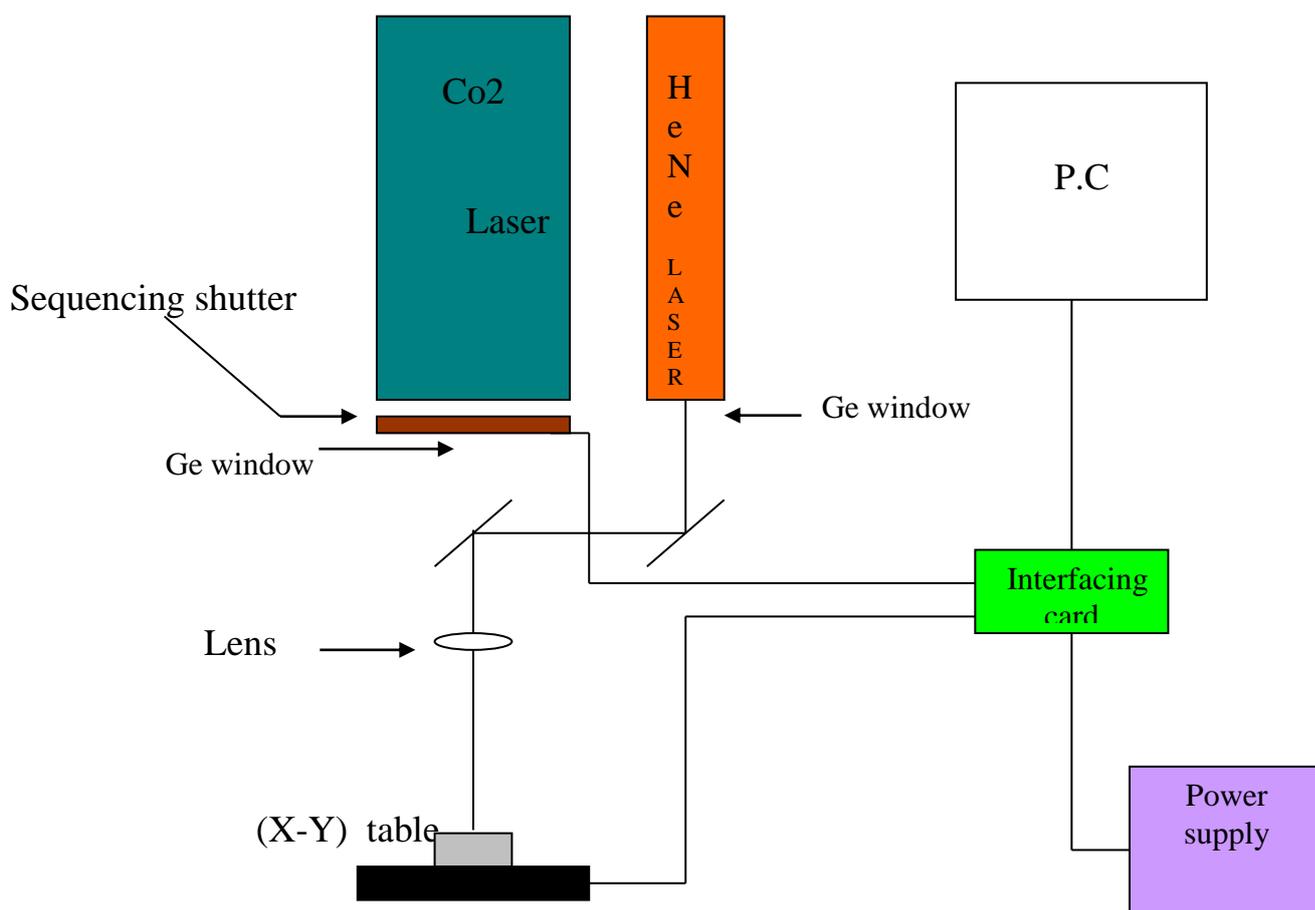
fig.(3.1) complete system block diagram

Table (3.1) specification of P.C

Type	Pentium III

CPU	800F
RAM	128
Manufactured by	ESCORT – Turkey

3.1.1 Designing of interfacing card:-

The full back diagram of the interfacing card is shown in Fig. (3.2). Several electronic chips are used to implement various system functions. This interfacing card is controlled by commands sent by the parallel port of the PC. . The complete interfacing card design is included.

$$g = 7 , n = 4 , r = 8 , e = 3 , \text{ and } c = 1$$

Fig. (3 .2) Block diagram of interfacing card

3.1.1.a Buffer circuit:-

The buffer circuit shown in Fig. (3.3) "Ic_1" was needed because of the limited driving capability of the P.C bus lines.

3.1.1.b Decoding circuit :-

The function of this circuit is to decode the address received from the computer memory by data bus lines D_4-D_5 during (I/o) read / write operations. A decoding circuit shown in Fig. (3.3) "$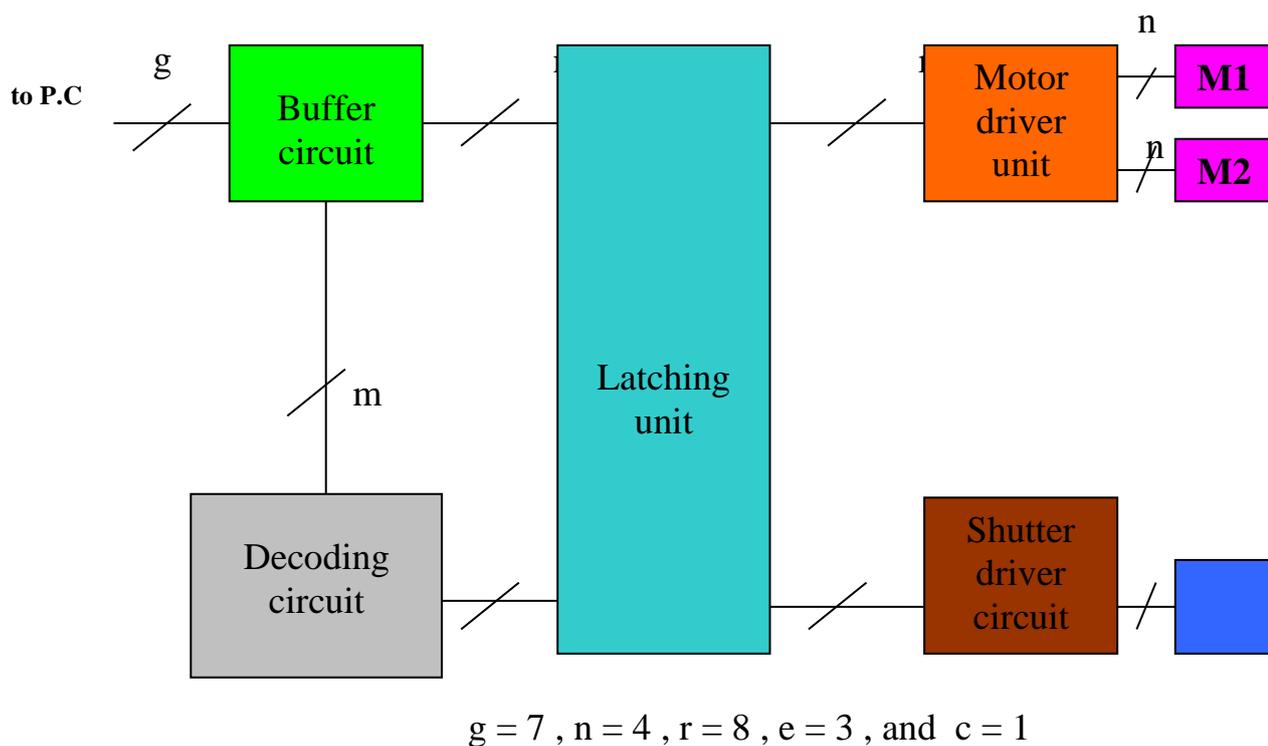Ic_2$", which is dual decoder circuit, was used to provide three c.s signals: the first two were used for the latching I.C chips of X and Y axis motors respectively and the last was used for the latching I.C chip of shutter driver circuit. The addresses of motor X-axis, Y-axis, and shutter driving circuit are 00,01 and 10 respectively.

3.1.1.c Latching unit :-

A latching unit shown in Fig. (3.3) (Ic3, Ic4, and Ic_5) was used to latch data received from the computer memory by data bus lines D_o – D_3. I.e. This unit was used as a memory. Each I.C latched the data when detected its C.K signal received from decoding circuit. This unit makes unactived parts latched at the previous position.

3.1.1.d Stepping motor driver unit:-

To achieve the best possible performance from a given motor, the driver characteristics must be tailored to suit the requirement of the motor. The drive implementation was done using a bridge power transistor type BD135 and additional passive components (resistors) as shown in fig. (3.3).

A transistor used as a switching on/off to turn on and off the windings in the stepping motor according to the sequence pulses received by data bus lines D_o-D_3.

3.1.1.e Shutter driver circuit:-

Turning the laser beam on/off can be controlled by the shutter driver circuit. A shutter driver depicted in fig. (3.3) "Tr_9" was used to active the shutter unit according to signal received from $I.C_5$.

3.1.2 Parallel port of P.C:-

A parallel port is an industrial standard interface designed for connected IBM printers to computer. It contains a 25-pin D type female connector. There are three general types of signal at the parallel port: Data, Control, and Status. The actual signals supplied at the pins of this connector are shown in table(3.2).

The MPU out puts data representing the character to be printed through the printer port. Character data are latched at the outputs of the parallel ports and are carried to the data inputs of the printer over data lines D_o through D_7, i.e. there are eight connectors used for carrying the data. Transfers the data

over this bus are synchronized with an appropriate sequence of control signals. [29].

Only six connectors of the data group and one connector of the control group were employed to handshake the P.C with the (X-Y) table and shutter circuit. The used connectors together with their corresponding numbers on the parallel port and their functions are listed in table (3.3).

Fig.(3.3) Interfacing card diagram
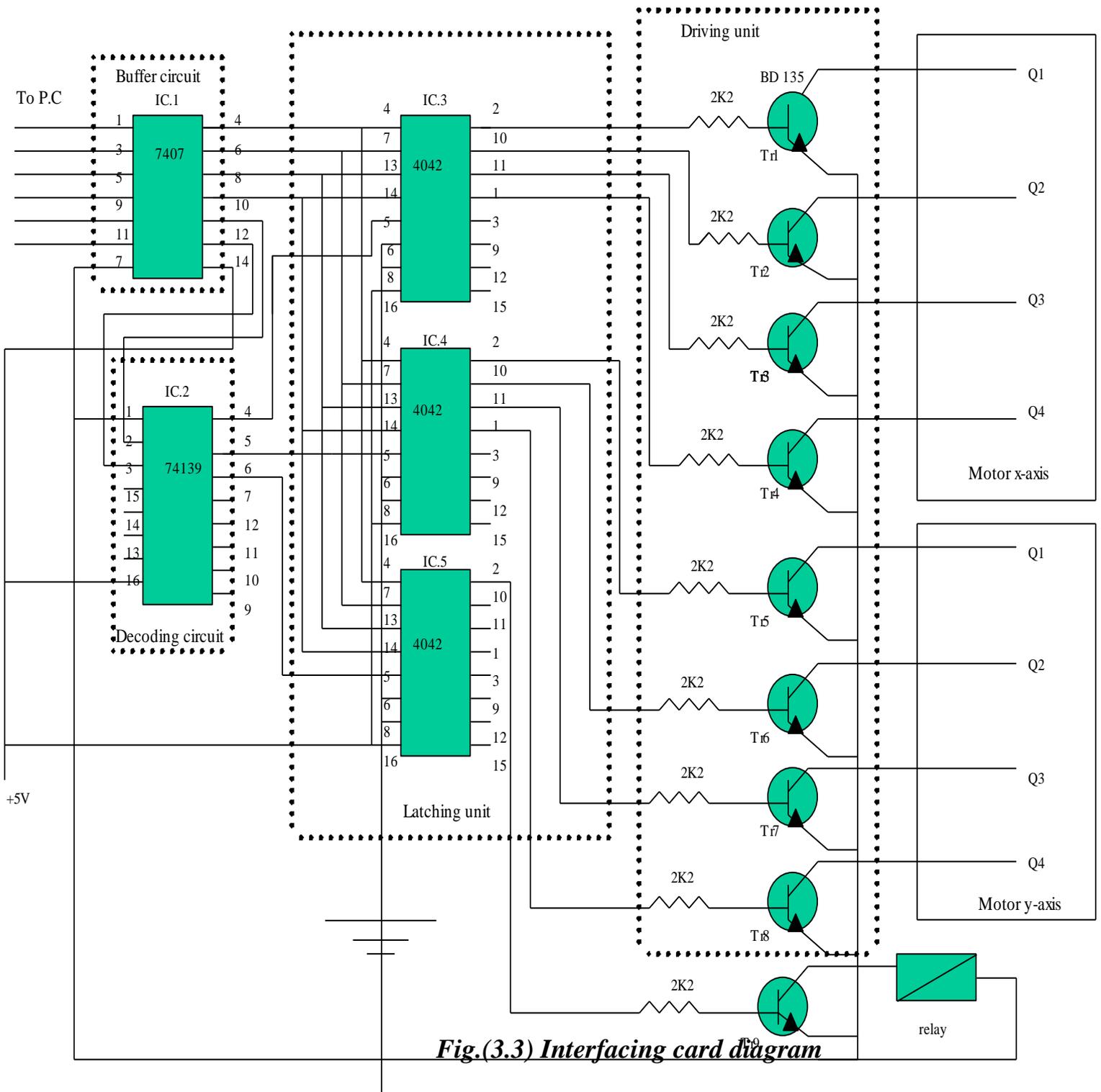
Table (3.2) Actual signals of the parallel port with their corresponding

numbers [27]

Pin	Assignment
1	strobe
2	Data 0
3	Data 1
4	Data 2
5	Data 3
6	Data 4
7	Data 5
8	Data 6
9	Data 7
10	Ack
11	Busy
12	Paper empty
13	Select
14	Auto foxt
15	Error
16	Initialize
17	Slctn
18	Ground
19	Ground
20	Ground
21	Ground
22	Ground
23	Ground
24	Ground
25	Ground

Data: Data 0, Data 1, …, Data 7

Control: Strobe, Auto Foxt, Initialize, and Slctn

Status: Ack, Busy, Paper Empty, Select, and Error

Table (3.3) The used parallel port connectors

Connector no.	Connector name	Type	Function
2	D0	Data	Generating Gray code counter
3	D1	Data	
4	D2	Data	
5	D3	Data	
6	D4	Data	Coding of Function address
7	D5	Data	

3.1.3 Stepping motors:-

The stepping motors form the central part of the project. Because of this, they must be motors of good quality, with precision and sufficient torque to move the work piece with out slipping or missing steps.

The motors used were of the four phases and so have permanent magnet rotor (permanent). Each motor has a single winding for each phase, so that the current is reversed through the phase coil to move the rotor one step. Specifications of these motors are listed in table (3.4).

The rotor can be made to rotate by successively energizing each of the four coils in turn, stepping around to face the energizing coils. Although the positioning of the coil and the shape of the stator allow 48 positions per revolution to be obtained by this method, if two adjacent coils are energizing in the following sequence (1,1+2,2…………then96) steps per revolution are obtained. This is improved by generating a half step drive sequence as shown in table (3.5). This type of sequence is called gray code sequence [47]. This technique made the stepping motor move half step (3.75) Deg. at each instant. The direction of rotation depends on the sequence direction either C.W or A.C.W. [31].

Table (3.4) Specifications of stepping motor

Step angle	7.5 Deg./step
Winding type	2-phase bifilar
Rated voltage	37.5 V
Rated current	0.25 A
Coil resistance	150 Ω

Table (3.5) Generating a half step drive sequence

Value (hexadecimal)	Q1	Q2	Q3	Q4	Step	Direction
9	1	0	0	1	0.5	CW ACW
1	1	0	0	0	1	
3	1	1	0	0	1.5	
2	0	1	0	0	2	
6	0	1	1	0	2.5	
4	0	0	1	0	3	
c	0	0	1	1	3.5	
8	0	0	0	1	4	

3.1.4 (X-Y) table :-

An (X-Y) recorder AMEL model 863 was used as on (X-Y) table. The purpose of this use is to reduce the high investment resulting from (X-Y) table implementation. This recorder is suitable for all requirements of the project.

The recording area of the recorder is (52*32) cm. A pen was replaced with a screw to fix up the base of the work piece fixture .The architecture of the recorder has two servo D.C. motors: one for the X- deflection, and the other to the Y- deflection. These motors were replaced with two stepping motors to suit the open loop system. As a result, the beam points down, while moving axes allow welding in any orientation.

3.1.5 Sequencing shutter unit :-

A strip of metal was used as a sequencing shutter, the safety shutter preventing unintentional laser beam. The laser beam is emitted through the hole in the center of a strip. This was improved by using a relay circuit where, activating a relay circuit will pull the shutter to pass the laser beam through the hole. A spring was attached to the shutter to be restoring it. A shutter unit is depicted in fig. (3.5).
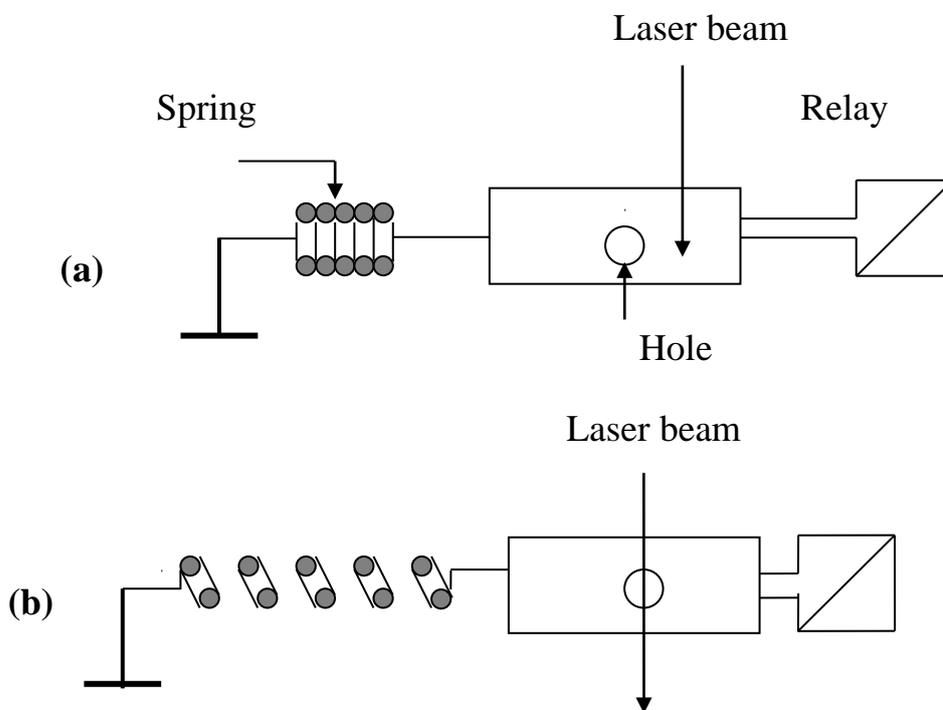
Laser beam

Spring   Relay

(a)

Hole

Laser beam

(b)

Fig.(3.4) Shutter unit : (a) opening shutter ; (b) closed shutter

3.2 Software design

In the previous section, hardware system was discussed in detail. The hardware is used by the system software to complete the control of the system functions. This software was programmed in C++ language operation under Dos environment. As will be shown in this section, most control functions are implemented by software rather than hardware due to the flexibility of the software solution for such a system. The basic system software is divided into two modules: -

1.   Manually controller module

2.   Local controller module

Manually controller module is used for detected the reference point (0,0) and the welding individual spots manually. On the other hand, local controller module is used for welding multi spots; such welding for inner leads to pin connectors of IC

The main program runs a number of functions consisting of a number of parts, which constitute the second part of the software.

3.2.1 Driver parts of program

3.2.1.a   Re – driving:-

This part will re drive the main program unless improving a definite condition. The flowchart of the part is shown in Fig. (3.5)
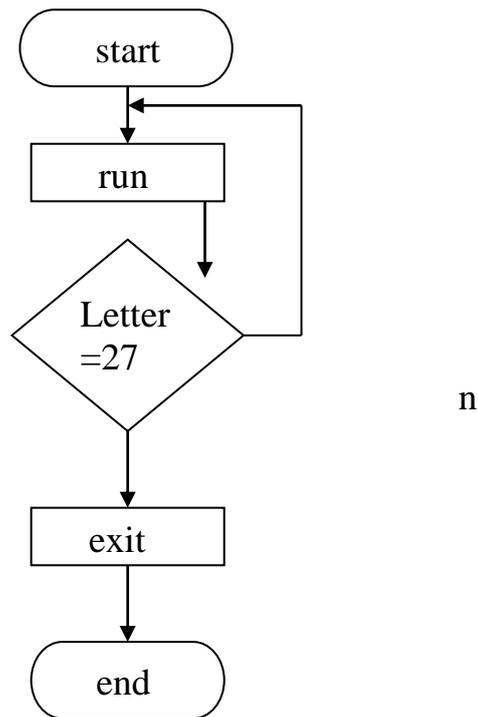
start

run

Letter =27

n

exit

end

Fig. (3.5) Re-driving part

3.2.1.b   Letters reading:-

This part reads letters and fetches its ASCII number. The part flowchart is given in Fig. (3.6)

Start

Read letters

Fetch ASCII number of letters

Fig. (3.   g part

Complete
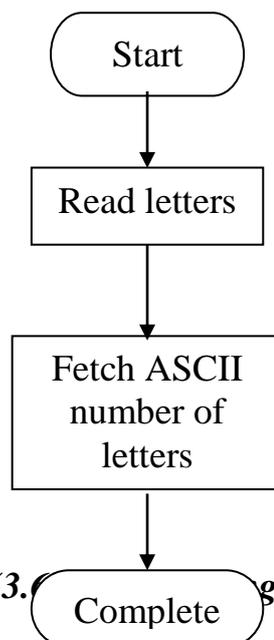
3.2.1.c   Process ....

The task of this part is to select one of six processes according to the letter inputted by the user. These processings are improving the table left, right, up, and down direction, releasing and closing the laser beam, and active local controller module. The flowchart of this subroutine is shown in Fig. (3.7)
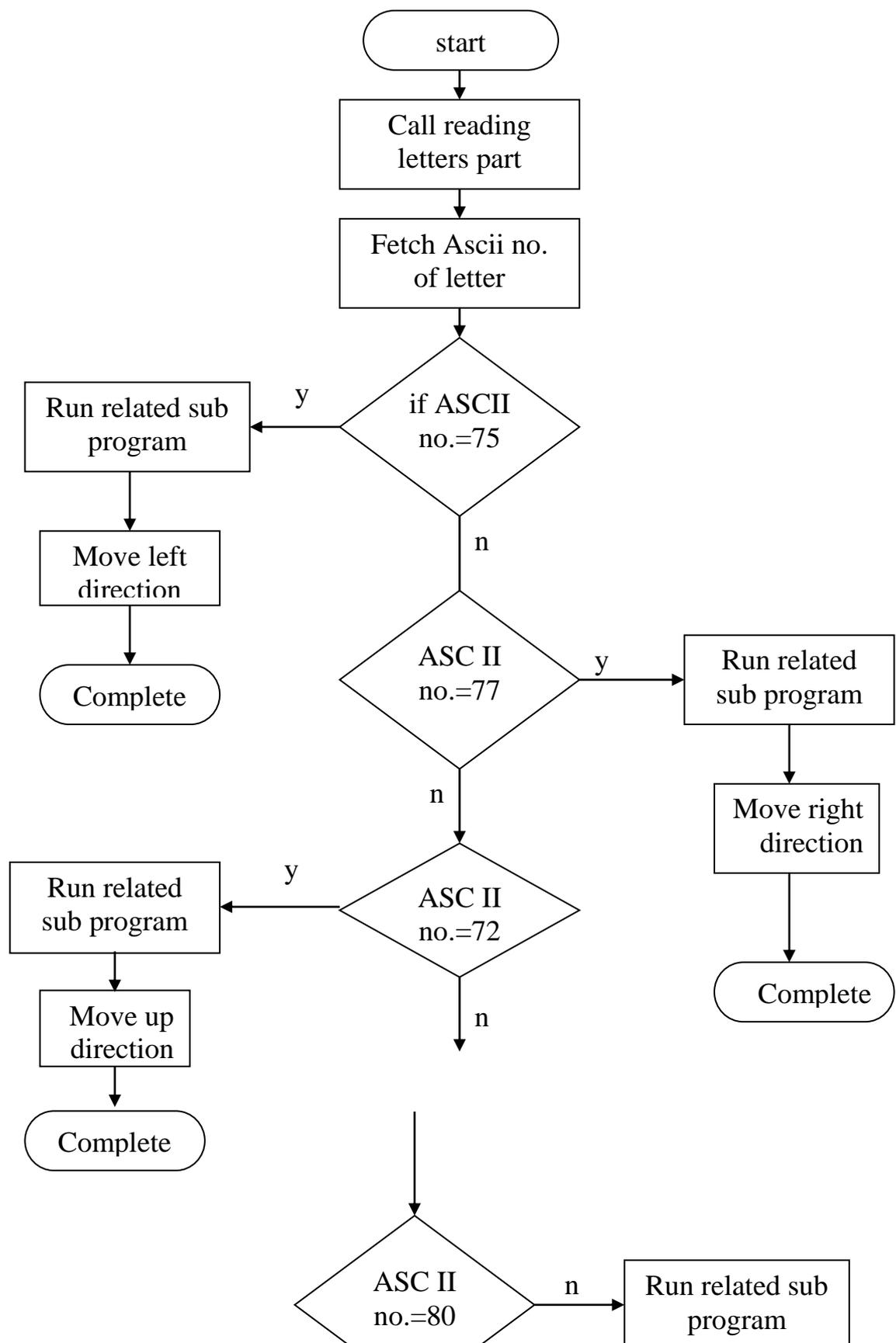
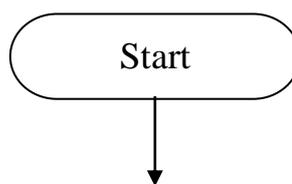| Move down direction |
| --- |

Fig.(3.7) process selection part

3.2.1.d Speed selection:-

This part is used to control the speed of the system. This subroutine will delay the program for interval time (ms), i.e., the speed is varied by changing the delay time at each required instant. The flowchart is depicted in Fig. (3.8)

Start

3.2.1.e Definition of weld duration:-

The task of this part is to define the weld duration according to time selected by the user. The related flowchart is shown in Fig. (3.9)

```
                    ( Start )
                        |
                        v
              / Input welding      /
             /  duration (D)      /
                        |
                        v
              [ Run related sub ]
              [    program       ]
                        |
                        v
              [ Delay the related sub ]
              [    program (D)ms       ]
                        |
                        v
```
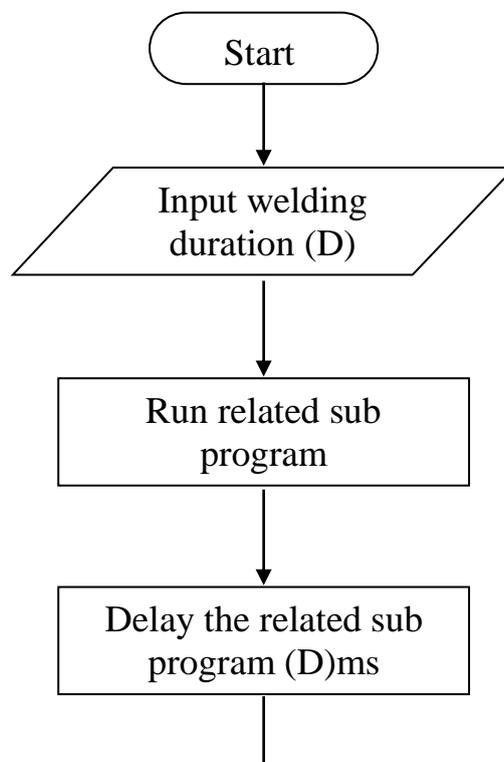
Fig.(3.9) Definition welding duration part

3.2.1.f Definition of work piece type:-

Using this part is to define the work piece type according to the letter selected by the user. The flowchart of this subroutine is shown in Fig. (3-1
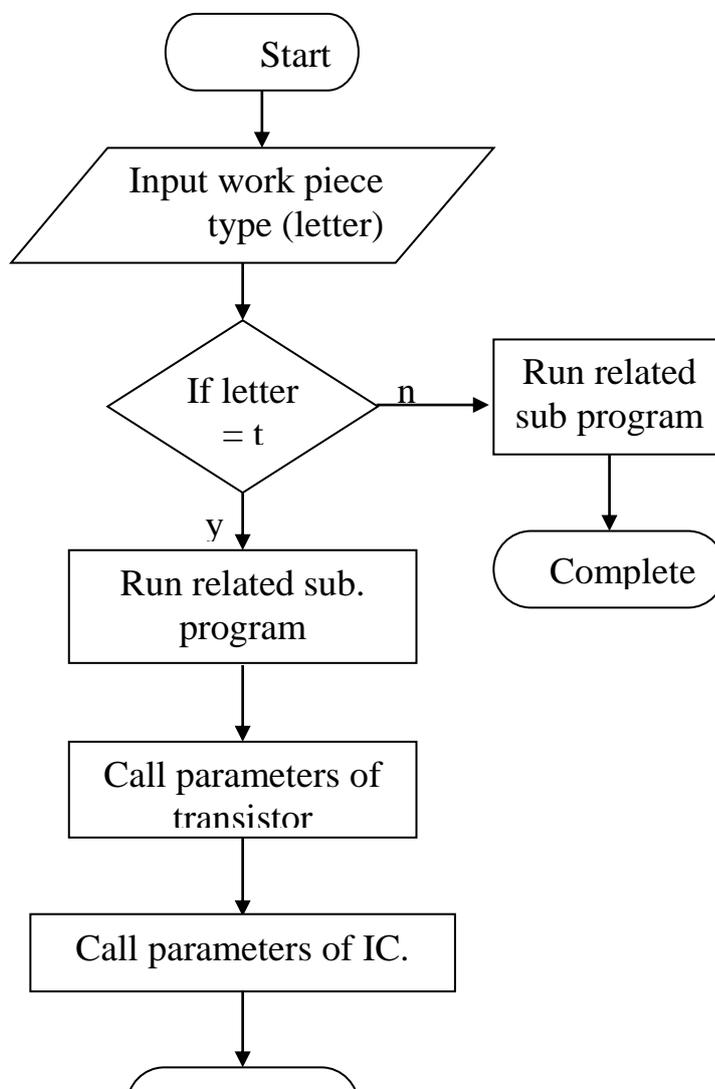
Fig. (3.10) Definition work piece type

3.2.1.g   Definition of the transmission distance on X- axis:-

This part is used to define the transmission distance between spots on X-axis where , this subroutine will define the rotation of X – axis motor according to the time defined by the user . The flowchart of this subroutine is depicted in the Fig.(3.11)
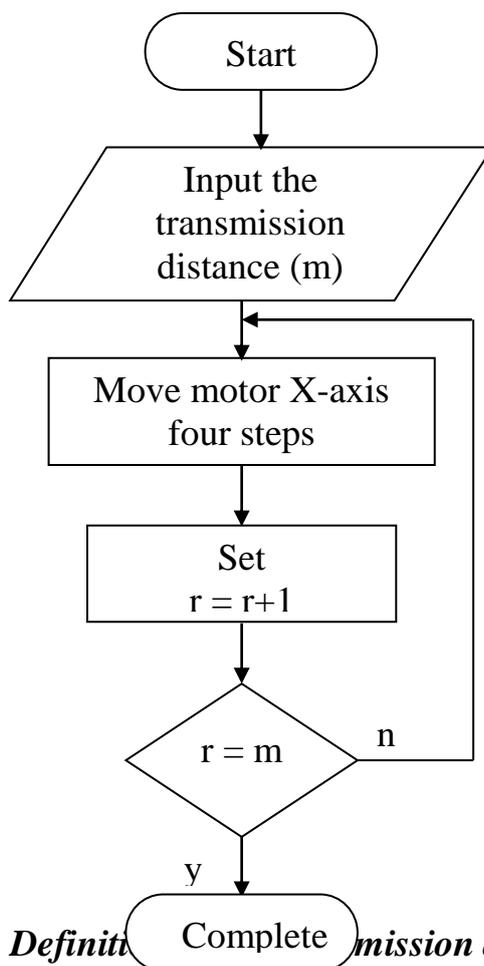
```
                    ┌──────────┐
                   (   Start   )
                    └────┬─────┘
                         │
                  ╱──────▼──────╲
                 ╱  Input the    ╲
                ╱  transmission   ╲
                ╲  distance (m)   ╱
                 ╲───────┬───────╱
                         │
                 ┌───────▼───────┐
                 │ Move motor X-axis│
                 │   four steps   │
                 └───────┬───────┘
                         │
                 ┌───────▼───────┐
                 │     Set        │
                 │   r = r+1      │
                 └───────┬───────┘
                         │
                      ╱──▼──╲
                     ╱       ╲   n
                    ╱ r = m   ╲────┐
                    ╲         ╱
                     ╲───┬───╱
                       y │
                    ┌────▼─────┐
                   ( Complete  )
                    └──────────┘
```

Fig.(3.11) Definition transmission distance on x-axis part

3.2.1.h   *Definition of transmission distance on Y- axis:-*

The task of this part is to define the transmission distance on Y-axis where, this subroutine will define the rotation of Y- axis motor according to the time selected by the user. The flowchart is shown in Fig.(3.12)
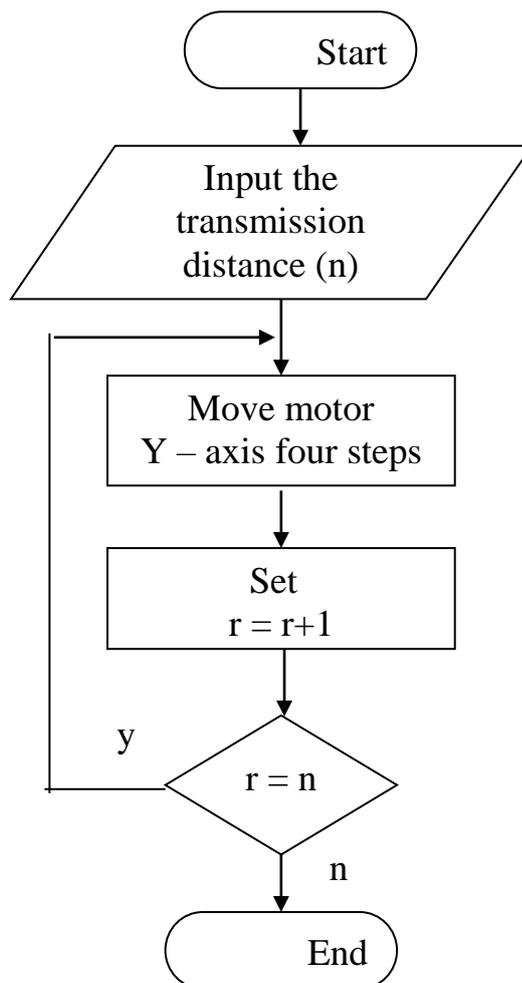
Fig. (3.12) Definition of transmission distance on y-axes part

3.2.1.i Definition of the weld spot number:-

This part will define the weld spot number according to the number defined by the user .The subroutine flowchart is given in Fig.(3.13)
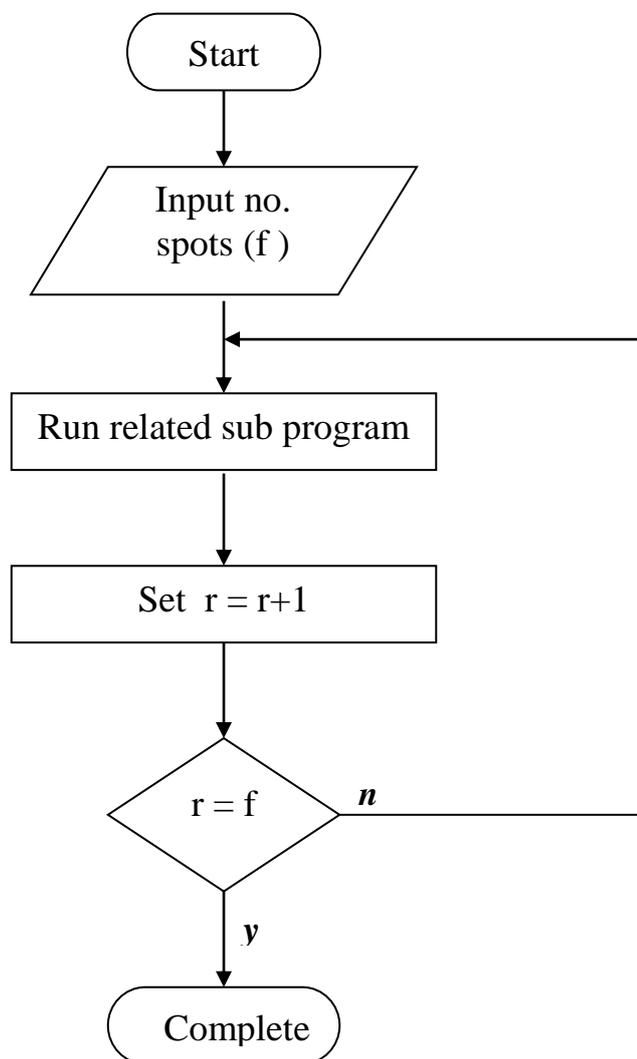
Fig. (3.13) Definition of the weld spot number part

3.2.2 Functional parts

3.3.2.a   Shutter driver:-

This part is used to drive the shutter for interval time selected by the user. The related flowchart is depicted in Fig.(3.14)
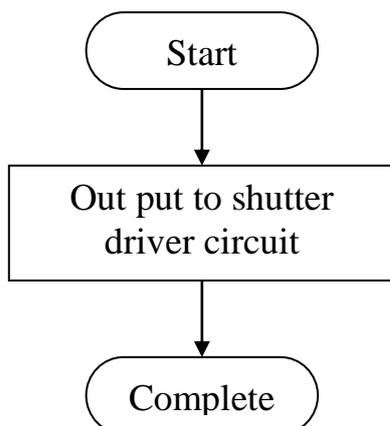
Fig. (3.14) Shutter driver part

3.2.2.b   Motor driver:-

The task of this part is to drive the stepping motors by generating consecutive pulses either CW or ACW. The flowchart of this program is shown in Fig. (3.15)
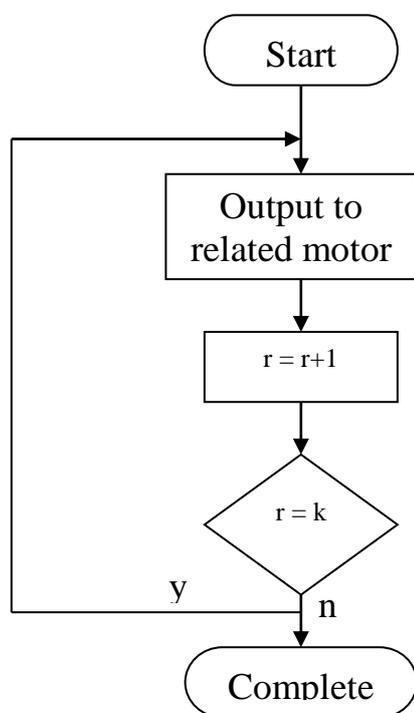

Fig. (3.15) Motor driver part

3.3   Usage of the system

A machine is on- line system therefore, the reference point (0,0) should be defined before welding process; driving the program will show the user the instructions how to use the machine. However, the reference point is defined by arrows of the keyboard. These arrows move the work piece left, right, up, and down directions. This technique can also be used for manually welding processes where, pressing W, letters will release the laser beam and pressing E letter will close it. Local controller module is actifed by pressing A letter. This module will ask the user about type of the work piece. The program will recognize the type of material by entering letters where, t and i letters term to transistor and I.C Respectively. When entering the reasonable letter, the program will ask the user about the work piece parameters. After entering all parameters, the program releases laser beam for interval time and closes it after having finished, then the work piece is moved beneath the laser gun and stopped to weld other spots.

4.1   *Results and discussions*

In this work, a computer controlled laser welding work has been designed, implemented, and tested. Fig. (4.1) depicts computer-controlled laser welding work station.

Welding processes have not been achieved because the power of the existing laser source is too low. However, the existing a (25-mw) C.W He-Ne laser was used to detect the weld position. Thus, a system was tested for several electronic components by transmitting laser beam on the work piece.

Testing of the system is included:-

1-   accuracy of (x-y) table

The accuracy of the table is ($\pm$ 0.5 mm). This value was detected by moving the table beneath the He-Ne laser beam for a several points and then return to the reference point (0,0). The distance between the start point and the final point represents the accuracy. However, this value is a very good results comparing with Al- azawy results in Ref. [26].

2-   Table speed

The table speed depending on processor speed of the p.c and the software program language. It good idea to design the softwore program in C++ language because the language is more appropriated flexible with this type of applications and fast than any another language. So, a maximum speed of a table is 6cm/sec, this value is rather than Al-azawy result in Ref. [26].
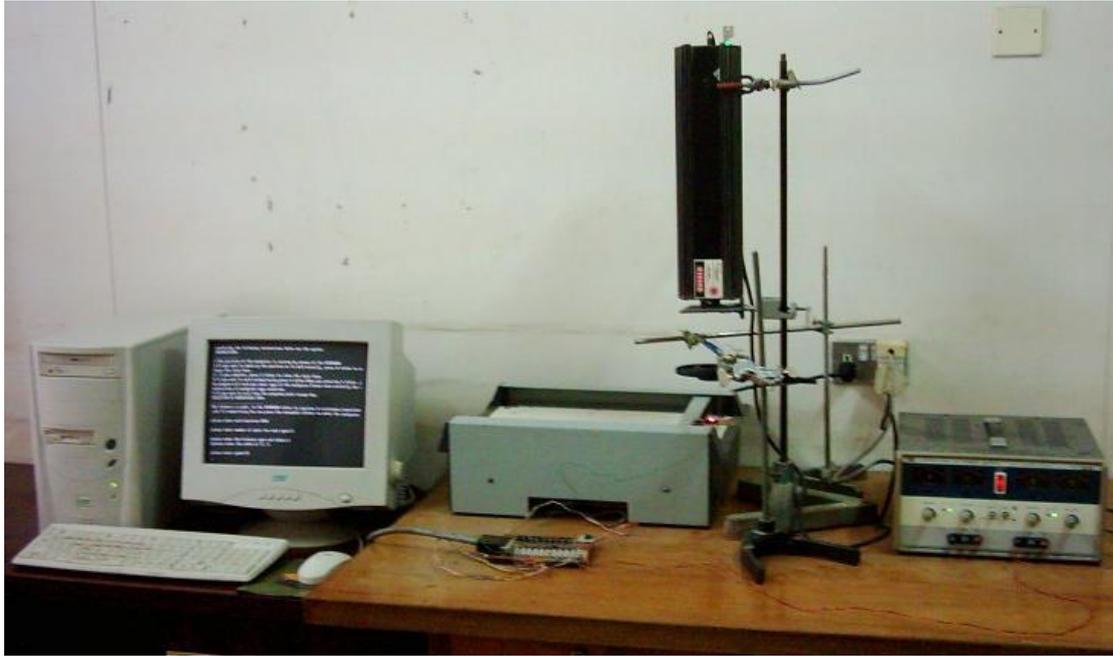
Fig.(4.1) computer controlled laser welding work station

The speed control is improved by the software program not by digital circuit by writing delay statement at each out signal command where, the maximum speed (6cm/sec) is done by delay time is 8. This technique allows flexibility and many range of speed selection.

To evaluate stability of speed of the table, the table was moved with a constant speed (2.4mm/sec) for several points at x and y axes. By dividing the distance to the time of the table movement for each point at each axes, the exact speed was computed as shown in table (4.1)

Table (4.1) The values of speed at different distance

Axes	Distance	Time	Speed
	4.1	1.7	2.41
X	8	3.2	2.5
	10.5	4	2.4
	12	4.85	2.47
	2.4	1.7	2.41
Y	7.5	3.2	2.5
	13	4	2.62
	17.6	4.85	2.47

Fig. (4.2) and Fig. (4.3) illustrate the stability of speed for each axes respectively. From two figures. we can see that the speed unstable for two axes, this happen because the accuracy of stepping motor and (x-y) table.

3. Operation parameters

A machine is on line system therefore, the reference point should be defined before welding process. However, the reference point is defined by the arrows of the keyboard. When detected reference point and then activated the local controller module, the program will ask about type of work piece and its parameters. For example, if we choose the I.C, the program will ask about the following parameters: -

1- weld duration :

2- number of spots :

3- distance between spots :

4- width of I.C :

5- speed of welding :

A basic length unit (BLU) of table is (2.5 mm), this value depending on the degree of step of stepping motor, driving mode, and conversion ratio of gears. BLU can be more reduced by driving a motor with micro stepping mode.

The motors of an x and y axes of the table was driving with a half stepping mode, that makes each motor have (3.75$^°$) step instead of (7.5$^°$) step and made stepping motors run many smother. As a result, the speed of the table increased from (4 cm/sec) to (6 cm/sec). So, the holding torque of stepping motor increases too. This result corresponding with Acarnly's in reference [16].
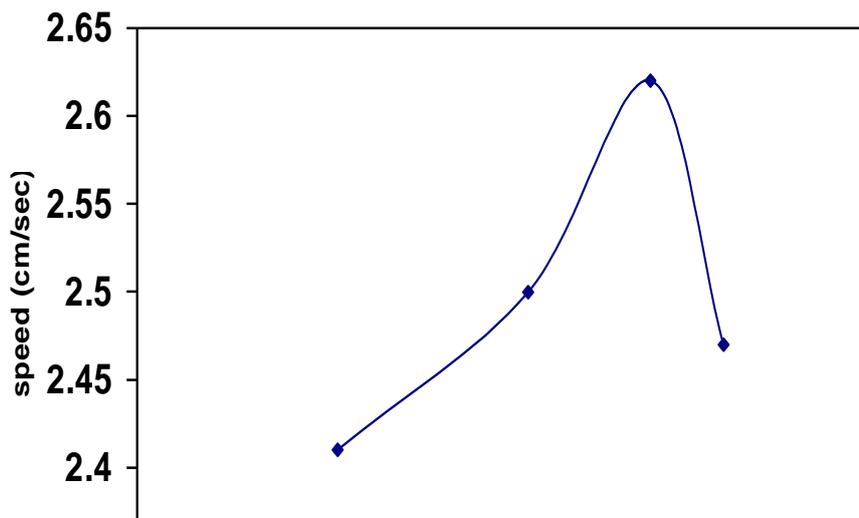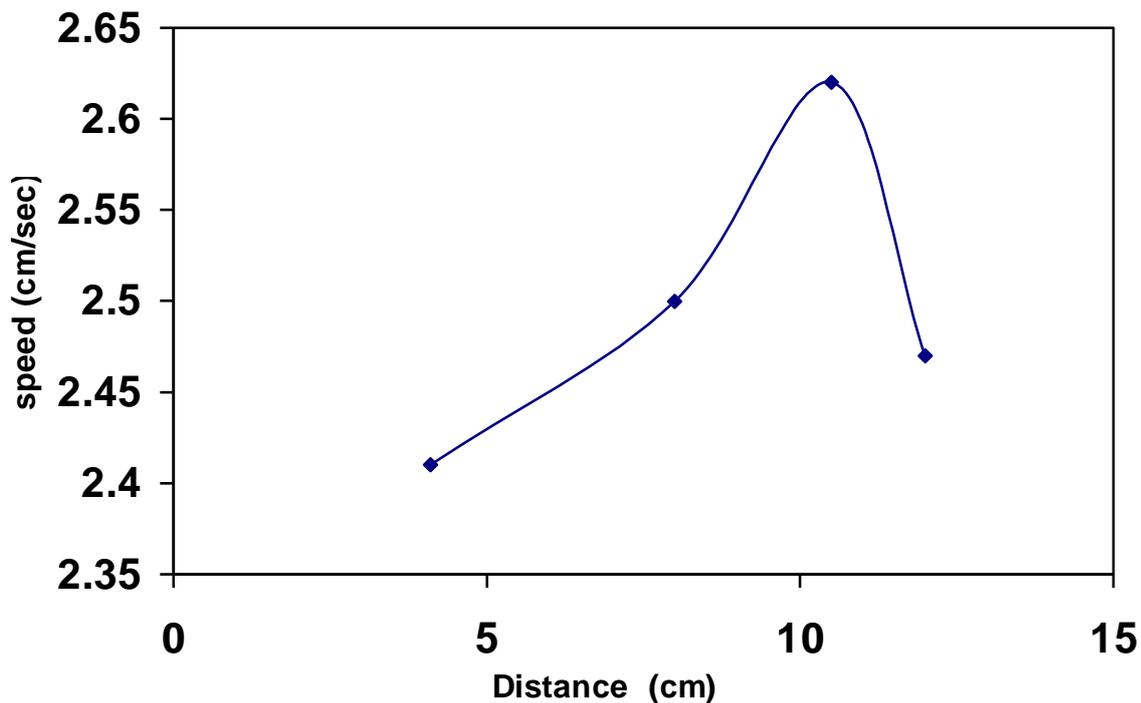
Fig. (4.2) Variation of stability speed in X-axis

Fig. (4.3) Variation of stability speed in Y-axis

4.2   Suggestions for future work

1. Implement a computer - controlled laser welding work station operating in closed loop system.

2. Implement a computer - controlled laser welding work station depending on moving the laser beam instead of moving the work piece by using optical fibre to transmit the beam in accessible areas.

3. Drive the motors of the table in micro stepping mode to obtain high resolution.

4. Drive the table with soft start, i.e., write many programs with acceleration mode at first and run fixed speed.

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