THE DESIGN AND FABRICATION OF AN AUTOMATED SHEAR STUD WELDING SYSTEM

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ABSTRACT

Stud welding is a process used in the construction industry to anchor concrete slabs to underlying steel substructures. This process is highly repetitive and, thus, a good candidate for automation. A robotic device, the Studmaster, has been developed which will automate stud welding currently done in the construction of industrial buildings. This machine, currently controlled by a microcomputer, utilizes a loading and welding mechanism which is fully actuated by only three pneumatic cylinders and one mechanical relay. This mechanism is mounted on a carriage which is manually indexed to each weld site by a human operator. An proposed version of Studmaster, costing $25,000 and using a single operator, is more productive than a crew of two using existing equipment and would pay for itself in eight months.

1. INTRODUCTION

There are a number of underlying economic motivations for investigating the automation of construction tasks. As labor costs continue to rise, new labor saving construction equipment becomes more cost effective. At the same time, the falling cost of microprocessors and related electronic equipment is driving down the cost of automated construction machinery. In many cases, product quality can also be improved when automated machinery is used.

Automation is most suited to repetitive tasks which are performed in a regular fashion and which require comparatively little judgement or experience. One such task in the construction industry is the welding of shear studs, also called shear connectors. Typically, an operator uses a semi-automatic "stud gun" to weld studs in rows on building or bridge decks, or on other structural steel members to be encased in concrete. With as many as 200,000 studs in a single building, the stud welding process is highly repetitive with little variation. And with well over 50 million studs welded annually, volume is high enough to make the automation of this procedure commercially viable. This paper addresses the development of a machine which helps automate the stud welding process.

2. BACKGROUND

Since the advent of the stud welding gun in the late 1950's, the use of shear connectors (studs) in composite construction has gained popularity. Building and bridge deck construction incorporates large numbers of studs, ranging from 10,000 to more than 200,000 at a single location. Figure 2.1 illustrates the basic process of studwelding.

The type of stud used in bridge and commercial building construction is a bolt-like piece of metal, usually about four or five inches long and three quarters of an inch in diameter, with a head that is about one and one quarter inch in diameter. Studs are welded through preformed corrugated steel decking to underlying steel substructures. Ferrules, small ceramic rings which fit around the studs at their bases, act as weld molds. Concrete is then poured over the studs and decking, effectively creating a composite structure. Figure 2.2 shows a sectional view of the components in a floor of this type.

Typically, two workers can place 2000 studs on a building deck in one day. One worker will lay out studs and ferrules (welding shields/molds) where the studs are to be welded, and the other worker will follow with a stud gun and weld them into place. The first worker, in turn, breaks the ferrules away from the studs. A significant amount of time is spent moving equipment and materials from one locale to the next and performing random testing to insure good weld quality. This testing usually means beating on the head of a welded stud with a sledge hammer to see if the stud will or will not break off at the weld.

Of the variety of shear stud applications in existence, it appears that building decks are the most likely candidate for automation based on volume alone. Of all the studs used in buildings and in bridges, 70% to 80% are used in buildings. The economic potential for automating the stud welding process in buildings appears to be much greater than that for bridges at this point. While the hardware described in this document is an automated stud welding system developed primarily for buildings, this system could easily be adapted for use on bridge deck construction.

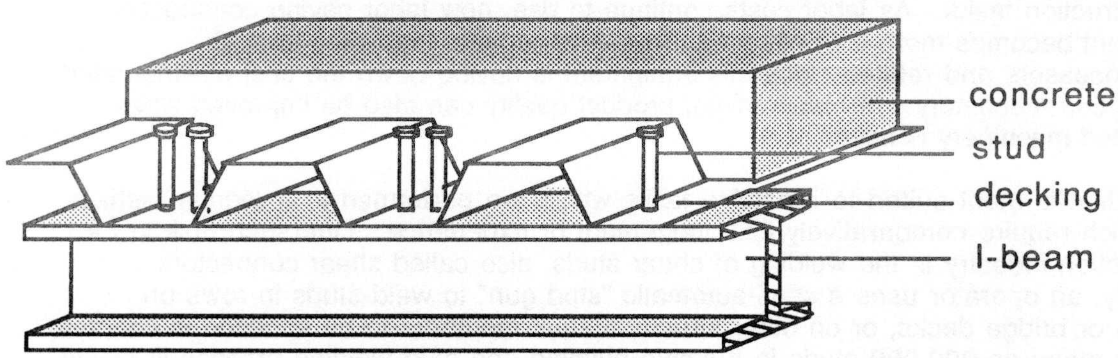

Figure 2.2 Drawing of Typical Floor Section in a Stud Welding Application

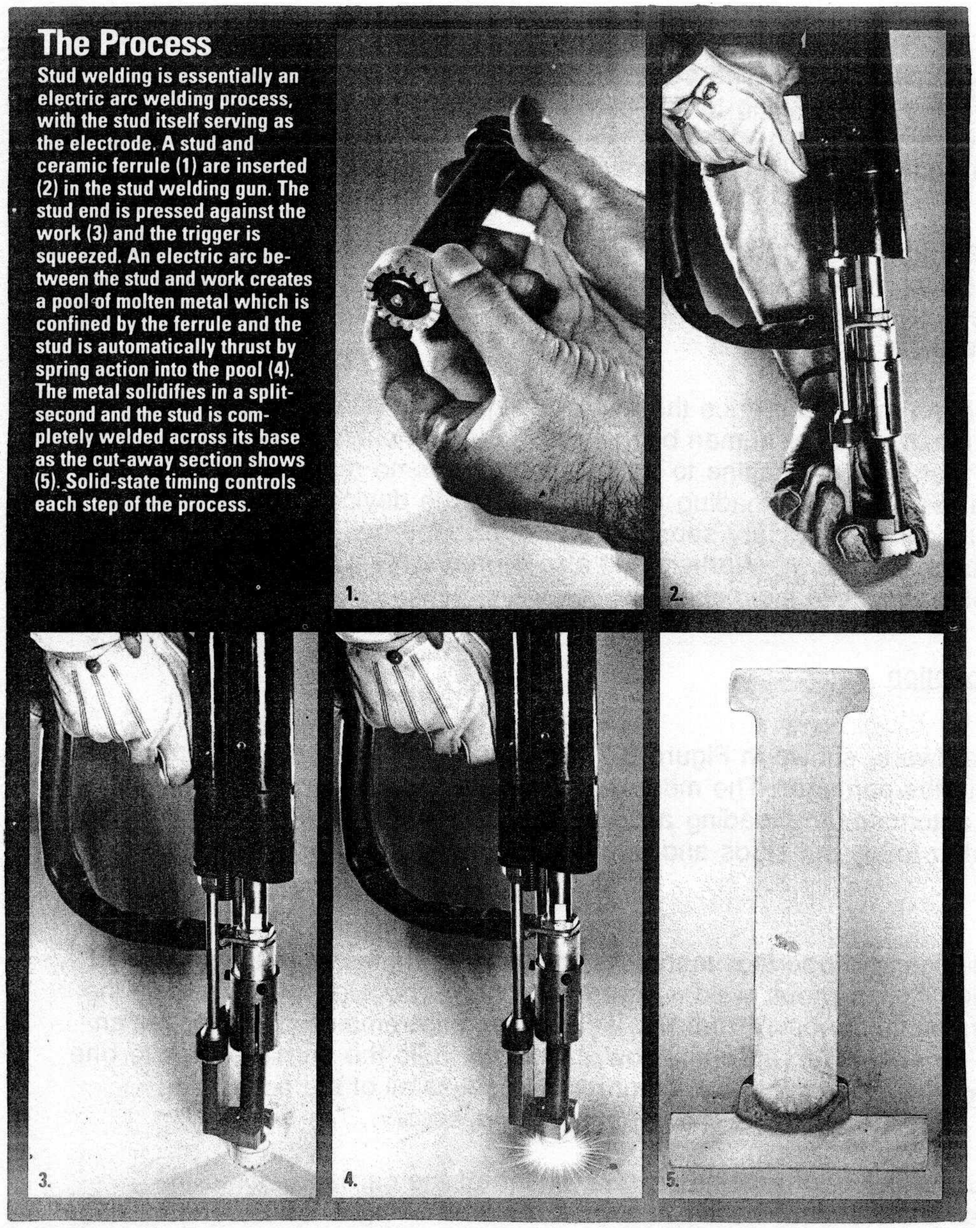

Figure 2.1 Stud Welding Sequence

3. MACHINE DEVELOPMENT

3.1 Design Goals

The goal of the work presented here has been to build a better tool for stud welding rather than to find a fully automated solution. It is the author's belief that a specialized, dedicated machine aimed at stud welding in a specific environment is more useful to the construction industry. Such a machine can be optimized to perform a specific task. There are far fewer tradeoffs leading to compromises in performance than for a machine

construction industry. Such a machine can be optimized to perform a specific task. There are far fewer tradeoffs leading to compromises in performance than for a machine designed to perform in a variety of different situations. A dedicated machine invariably is simpler and easier to use than a more generalized version.

In keeping with the theme of simplicity, every effort has been made to minimize the number and complexity of motions executed by the Studmaster. The goals behind this effort are to reduce machine costs and downtime as well as to create a machine that won't be intimidating to use.

While efforts have been made to reduce the negative aspects of human operation from Studmaster, by no means has the human been removed from the cycle. Because a worker must be on site to monitor the machine to begin with, there is no reason that he or she should not perform tasks such as loading and positioning the device. With the worker in the control loop, otherwise necessary sensors for the machine can be eliminated, thus keeping cost and complexity low. Workers will also be more receptive to a machine which does not pretend to make them obsolete.

3.2 Machine Description

The Studmaster hardware, shown in Figure 3.1, consists of two main components: the welding module and the carriage. The module, built around a modified version of an existing stud gun, automates the loading and welding functions. Through this automation, the need for a worker to lay out studs and ferrules at the welding sites in advance is eliminated.

With the current design, the operator manually advances Studmaster to the next weld site after completing the previous weld. Along with the responsibility of indexing the machine, the operator must ensure that the welding module remains directly over an underlying beam. After welding an entire row, he or she rolls the carriage over to one end of the next row and proceeds to weld that row. Because all of the positioning movements of the welder are manual, no sensors are necessary.

There remains the possibility of automating the motion of the carriage along one dimension, that being the direction travelled while a row is being welded. The carriage could be driven by a motor which is controlled by sensors detecting the locations of weld sites.

Studmaster is designed to carry as many as three welding modules on a single carriage. While multiple welding modules add some cost, weight, and complexity, they significantly increase productivity by reducing the ratio of travel time to weld time. Three welds would be made in rapid succession each time the carriage stops. After the welds are made, the carriage would then move past these three sites to the next three. In effect, the operator would have to index the machine one third as often as a one-module machine for a given number of studs. Since this indexing is probably the most time-consuming portion of the weld cycle, the increase in machine cost would probably be offset by increases in productivity. The prototype machine has a single welding module which is sufficient because it is conceptually similar to a multiple module system.

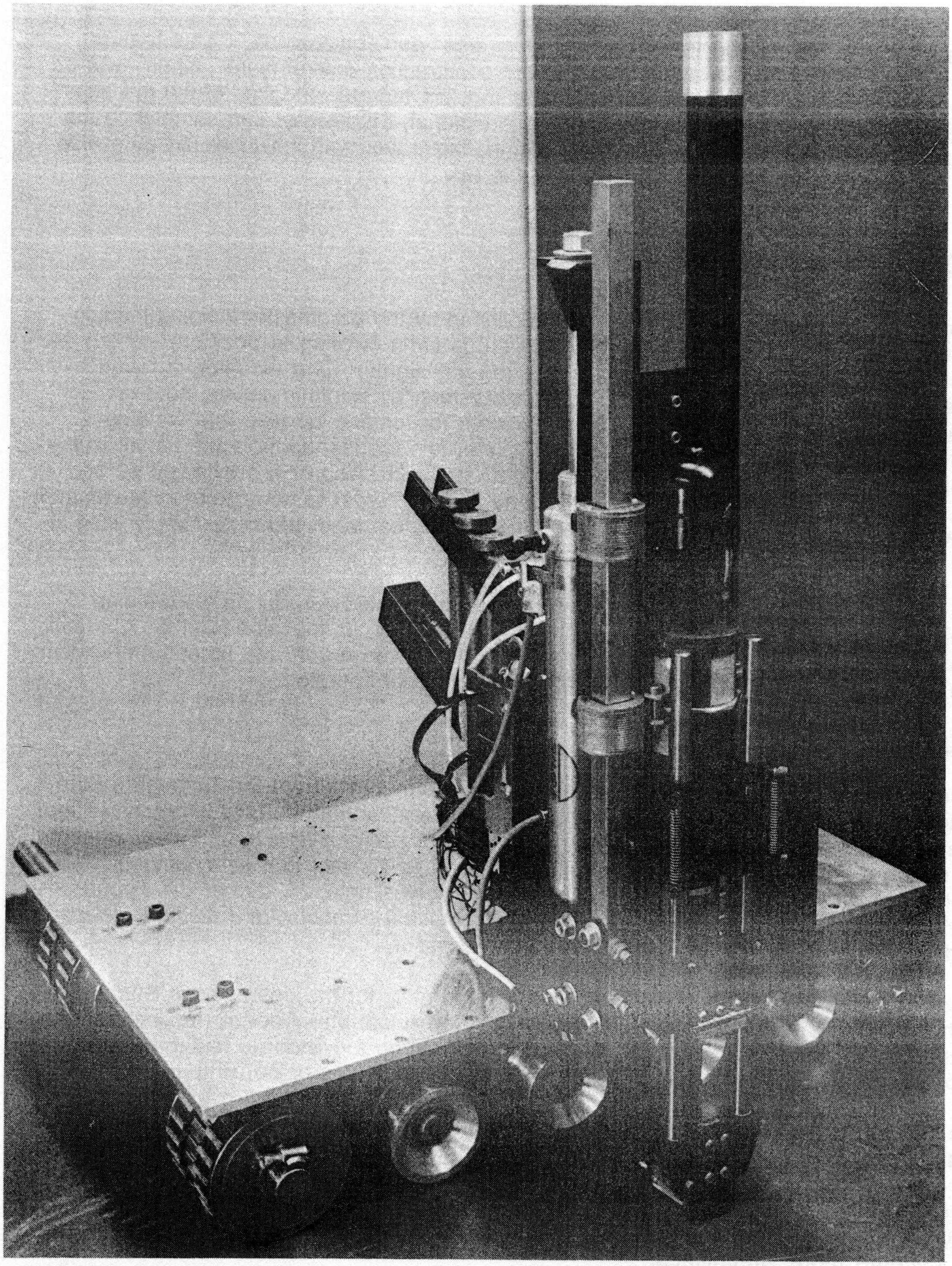

Figure 3.1 Overview of Studmaster Hardware

Studmaster can weld while travelling both "forwards" and "backwards." This feature makes Studmaster more versatile to use in the construction environment. Often rows of studs must be welded along obstacles of some sort, leaving only one side of the row clear for navigation by the welder. Because it is bidirectional, Studmaster can commence the welding of the row from either end, thus eliminating travel time which would otherwise have to be spent getting to the proper end of the row.

3.3 Welding Module Hardware

To accomplish the three basic actions accomplished by the Studmaster welding module - loading studs; loading ferrules; and welding studs (with ferrules in position) - there are only four actuators, each driven by a digital (on-off) signal. One actuator, a relay, triggers the welding mechanism. The other actuators, all solenoid valves, control pneumatic cylinders. One cylinder is responsible for loading ferrules into welding position, another loads studs into welding position, and the last controls the height of the welding mechanism, allowing it to clear the corrugated decking or a previously welded stud during movement from one weld site to the next. In order to power the solenoids and cylinders, a small accumulator will be mounted on the carriage, fed by a supply line from a compressor somewhere at the building site.

Due to the large amounts of current flowing through the stud gun during the welding process, every effort has been made to insulate the rest of the machine from the gun and from the ground. There are at least three conductive barriers to any potential electrical path between the gun and ground through the machine or operator.

3.4 Control

At this stage of development, the operator directs the machine from the keyboard of the computer, an I.B.M. AT. In the computer is a program, written in C, which receives the operator's commands and sensor signals, interprets them, and directs an output signal to the external system through a digital I/O port. Due to the fact that everything (so far) is either in an "on" or "off" state, the circuitry is very simple. A further developed version of Studmaster would dispense with the personal computer and digital interface card, replacing them with an embedded microprocessor.

There are 3 sensors necessary (along with an operator) for the operation of Studmaster: a photoelectric sensor to ensure the presence of ferrules; an inductive proximity sensor to ensure the presence of studs, and a reed switch set on a cylinder to test if the welding mechanism is fully raised. All three sensors give digital (yes or no) outputs.

The controlling software was written in C in a modular style so as to maximize portability and adaptability. The main module contains a menu of functions from which the operator can choose. As these functions are called, they in turn may call one or several others to execute the task at hand. Currently, the function menu is fairly large to assist the operator in mechanical debugging. As the hardware is refined, the menu will become more streamlined.

Unlike the current stud guns, each of which has a power cable and a control cable trailing behind it, Studmaster has a larger umbilical cord which consists of a power cable, two control cables, and a pneumatic supply hose. One of the control cables runs between the gun solenoid and the weld controller, and the other links the sensors and actuators to the interface box which currently resides near the computer.

4. ECONOMIC ANALYSIS

For any new process to be successfully adopted, it must be proven to be clearly superior to the one it is designed to replace in terms of productivity and quality. A new system like Studmaster will have to pay back its initial investment quickly and continue to provide a substantial rate of return.

In order to assess the economic potential of both a one welding module and a three welding module version of Studmaster, an economic comparison was made between the current manual process and both potential versions of the automated system. It is assumed that, when operating, the one module version of Studmaster is capable of welding at a rate of about one stud every five seconds, roughly as fast as a human using current equipment. The three module version is assumed to weld at a rate of one stud every three seconds, due to the decrease in travel time. In both cases, the machines are assumed to operate for 25% (two hours) of one shift per day. Purcahse price of a one-module version is estimated to be $15,000 and $25,000 for a three-module version. Maintenance costs are expected to be 30% of purchase price per year, and predicted life time is five years.

Given these assumptions, our calculations show that a one-module version could save about four cents per weld and the three-module type could save nine cents per weld. This translates to a payback time of 23 and eight months respectively. Based on these figures, the concept of autometed stud welding in a construction environment certainly warrants further development.

5. CONCLUSIONS AND RECOMMENDATIONS

Based on the results of our field testing, it seems clear that Studmaster is a viable concept. However, there are several aspects of the machine which require further investigation, development, and refinement before it can be a commercially useful item. Following are a few areas which the author currently believes to be either inadequate solutions or not fully solved problems.

There was some difficulty in manually indexing Studmaster accurately over new weld sites. The apparent causes of this difficulty were the weight of the machine and the lack of a good visual reference point. Both of these problems are not difficult to solve.

Even though the stud loading mechanism in the weld module works quite well, there is not yet a simple, rapid means by which to take studs from the box in which they are shipped and load them into the holding rack on the machine. This process is currently time consuming and cannot be accomplished while the machine is in operation. A better means by which to load studs and a larger capacity rack on which to hold them are needed.

At this time, there is no provision on Studmaster for breaking away ferrules once they have been used for welding. It is believed that a solenoid plunger mounted near the end of the weld gun assembly would effectively and consistently break the ferrules away.

One possible alternative to the ferrules currently employed is the use of reusable ferrules, similar to those which are currently used with smaller automatic stud welding machines. If a suitable material can be found which is heat resistant and not prone to residual buildup, then a reusable ferrule may be an attractive alternative to the disposable ones currently used.

Mechanically as well as electronically, the prototype Studmaster described in this paper is not robust enough to operate for long in a heavy construction environment. The next version must to be stronger and its electronics better insulated from the huge surges of current flowing through the welding gun.