THE EFFECTS OF OPTIMIZED THERMAL CHARACTERISTICS IN RESISTANCE WELDING TRANSFORMERS

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ABSTRACT

THE EFFECTS OF OPTIMIZED THERMAL CHARACTERISTICS IN RESISTANCE WELDING TRANSFORMERS

This paper will investigate the effects of design variables on the thermal characteristics of a resistance welding transformer. The resistance welding transformer has many design characteristics that interact. This study will look at a transformer design that has an optimized thermal rating and how this design affects KVA, ECTC, impedance, and short circuit secondary current. The study will also look at non-thermal characteristics such as size, weight, excitation current, secondary voltage, and several other system variables. By choosing to optimize the thermal characteristics, several other design characteristics can be dramatically affected.

As system integrators and end users look for certain performance criteria from resistance welding transformers, it becomes important that these individuals are aware of how optimizing a specific characteristics will affect the electrical system within the welding tool.

It is the intention of this paper to simplify electrical engineering principles, specifically as applied to resistance welding transformer design. It will demonstrate how certain transformer characteristics affect the welding process, tool design and transformer performance.

INTRODUCTION

The paper written for the 1996 SMWC VII, entitled “Comparison of Internally Parallel Secondary and Internally Series Secondary Transgun Transformers” detailed some performance shortcomings in the existing series-style transformer. The major disadvantage of the series-style transformer was that of thermal capacity or the ability to produce an adequate number of welds per minute at a specified current level.

With the industry trend towards the use of more transgun style transformers and the desire to avoid using hip-mounted portable gun transformers with kickless cables, there seemed to be just cause to investigate the optimization of the thermal characteristics in the transgun transformer.

The transformer chosen for the research was the “5 x 6 ¾” transgun style transformer. This transformer is currently the standard size transgun style transformer for both General Motors and DaimlerChrysler and is also a RWMA standard transformer, which, combined, represents the largest volume of transgun transformers in North America.

A general trend in automotive resistance welding tool design is toward flexible automation in which a welding cell may see multiple styles of vehicles; this produces a large variety of weld schedules and also tends to push the production rate of any given cell higher.

The intent of this paper is to look at industry requirements of transgun transformers and the effect of performance and design on the welding transformer.

BACKGROUND

A recent new vehicle launch at a North American assembly plant highlights the extreme requirements put on modern day welding tools. This specific welding cell was designed to be able to produce two different style vehicles. The most severe welding condition required an average secondary current of 18.1 KA and was producing 33 welds in a one-minute period of time with an average weld time of 14 cycles. Using an industry standard series secondary transformer rated 90 KVA with a 16 volt secondary, the KVA requirement for this specific job was approximately 147 KVA at 50% duty cycle! This requirement was 40% more than the rating of the existing transformer. To reprocess this job and move welds and add robots or change the transguns to portable guns would be very expensive and would have a negative impact on the production rate.

It is this type of true story that initiated this research. The criteria was to take the 5" x 6 ¾" transgun transformer and increase its thermal capacity without changing the outside physical dimensions. The 5" x 6 ¾" transgun transformer is currently produced in both an internally parallel secondary version and an internally series secondary version. With large guns and high secondary current requirements, the series secondary version of this transformer becomes the most widely used. With the combination of a high secondary current and a high secondary voltage, the demand KVA becomes a critical variable in the transformer selection process. This is best illustrated by studying the following basic equations.

Equation 1 $KVA_R = KVA_D \times (DC/50)^{1/2}$
where
KVA_R = The rated KVA of the transformer @ 50% duty cycle.

Equation 2 KVA_D = The weld current x secondary maximum voltage

Equation 3 DC = duty cycle = (welds per minute x weld time/60 x freq) x 100%

Notes: Weld time is in cycles, the frequency for all calculations in this paper is 60 HZ.

A manipulation of Equation 3 can solve for either weld cycles per minute, or choose a weld time and solve for welds per minute. When looking at the thermal capabilities of a resistance welding transformer, two basic principles must be studied; (1) the heat produced in the primary and secondary winding and (2) the heat transfer to the cooling media. Both of these principles will be discussed further in this paper.

EVOLUTION FROM FIXTURE TYPE TO TRANSGUN TRANSFORMER

The welding of automotive body parts has changed dramatically during the last 20 years. Typically, the welding was done in large welding press lines. These lines, sometimes referred to as hard automation, were generally dedicated to a specific body part. The welding equipment used were fixture-type transformers, (also known as multispot or package type transformers), air-cooled jumpers, air operated welding cylinders, and tooling in the form of electrodes, backups, etc. Often, transformers were grouped together and controlled by a single welding control. Tap switches were provided to have a limited adjustment for differences in welding loop configuration. At times, it was necessary to fire a transformer with the secondary open within a group of transformers connected to the same control. The reason might have been reduction of primary demand or a weld was not required for a specific part. In many cases, a weld circuit made only one weld per part and thus, most welding transformers operated well below their thermal or KVA rating. Welding controls in use 20 years ago lacked some of the features and accuracy of today's controls, which means the transformers had to accept some unbalance in primary current (saturation of the magnetic core), inaccuracies in timing of the weld sequence, etc. In summary, fixture-type transformers experienced a low thermal load, but had to tolerate operating conditions which stressed their magnetic circuit. The design of fixture type transformers was based on meeting these requirements. Today, robots with transformer-weldguns (also called transgun units) mounted to their wrist are widely used in place of the above described hard automation. As the word transgun suggests, the transformer and weldgun are mechanically integrated into one unit. This allows a close and short electrical connection between the transformer and weldgun, thereby eliminating the electrical losses inherent in welding circuits using air-cooled jumpers. The result is a more efficient welding tool. However, because of the placement of the transgun on the wrist of the robot and the fact that many welds per part can be accomplished in this arrangement, new and different demands are placed on the transgun transformer.
These demands can be summed up as follows:

1. The transformer must be as light as possible to allow fast movement of the robot.
2. The transformer must be as small as possible to allow close mounting with the weldgun.
3. The transformer must have a high KVA rating for its weight and size.
4. The transformer is not required to operate with the secondary circuit open.
5. The transformer should be interchangeable with existing transgun transformers.

To accomplish these requirements, the thermal and magnetic characteristics of the transformer must be analyzed and an optimum solution found. The most obvious approach is to improve the heat transfer characteristics between the windings and the cooling media. This step yields increased thermal ratings, yet not sufficient to meet the requirement.

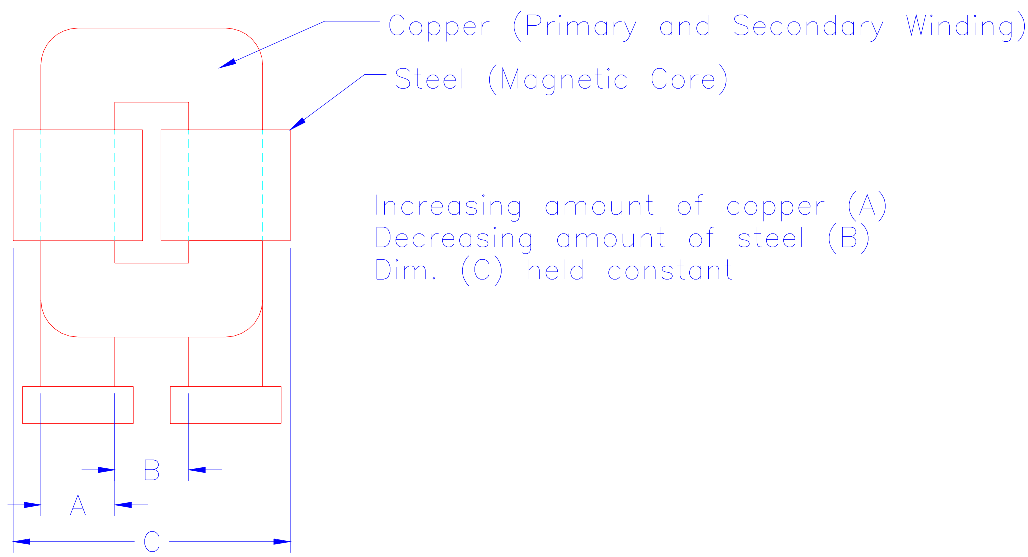


Figure 1. Basic Internal Construction

The next step is to change the ratio of copper to magnetic core volume of the transformer. The copper volume affects the size of the primary and secondary windings and the magnetic core volume affects the size of the magnetic core. In the case of transgun transformers, the optimization was accomplished by increasing the copper volume and decreasing the magnetic core volume (See Figure 1.). The increase in copper volume results in increased KVA rating, increased short circuit current, and a lower impedance.

The decrease of the magnetic core volume results in a higher excitation current due to the higher flux density at which the magnetic core operates. However, one must differentiate between the excitation current under **no-load** and **loaded** condition of the welding transformer.

Under no-load condition, the excitation current is the only current flowing through the primary winding of the transformer, thus creating a small voltage drop in the primary winding only. The electro-motive force, also called EMF, produced in the primary windings by the magnetic flux in the core and the voltage drop produced by the passing through the impedance of the primary winding must equal the voltage applied to the primary of the transformer. Due to the small voltage drop of primary windings' impedance, the EMF nearly equals the applied voltage. This condition leads to a formidable high excitation current to generate the required magnetic flux and EMF under no-load operation. As mentioned before, the no-load operation of transgun transformers does not occur in normal operation and thus, we can safely apply a higher flux density or reduce the magnetic core volume in the design of transgun transformers. To support this statement, figure 2 thru 6 shows relations between the magnetic flux, EMF and excitation current under welding operation, which represents the load condition. Under load condition, the weld and excitation current flows through the primary winding of the transformer. (Note: The weld current in the primary winding is obtained by dividing the secondary or actual weld current by the turns ratio of the transformer.) The vectorial sum of weld and excitation current is called the load current. This load current produces a sizeable voltage drop in the primary winding. As discussed under the no-load condition, the voltage drop in the primary winding along with the EMF induced in the primary winding must equal the voltage applied to the primary. Thus, the higher voltage drop leads to a reduction of the EMF, magnetic flux and excitation current. By carefully optimizing the copper and magnetic core volume, a transformer can be designed yielding superior thermal and impedance characteristics and at the same time satisfy all other operational conditions.

The following pictures and diagrams support the foregoing discussion showing the conditions of “no-load” and “load” of the transformer. To achieve a clearer and better understanding, simplifications have been made. Specifically, the resistance and reactance of the windings have been combined to an impedance and the core loss has not been considered.

NO-LOAD

A. SCHEMATIC DIAGRAMS

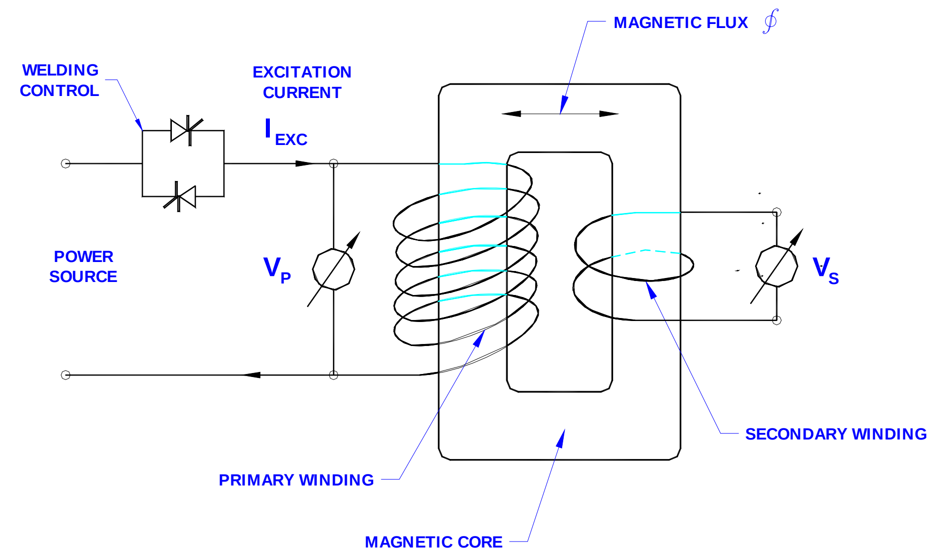


Figure 2.

LOAD

A. SCHEMATIC DIAGRAMS

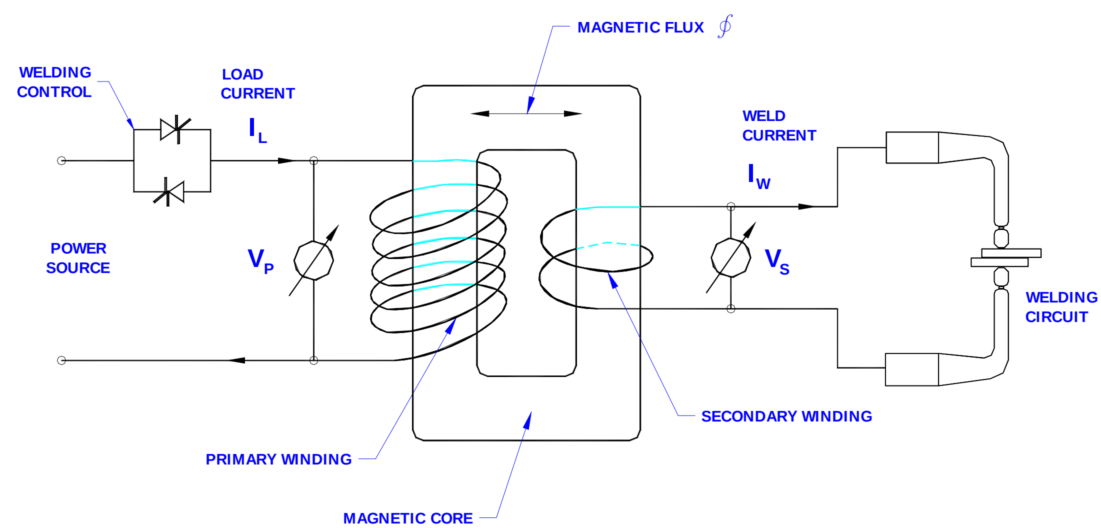


Figure 3.

NO-LOAD

B. ELECTRICAL EQUIVALENT DIAGRAM (BASED ON A 1:1 TURN RATIO)

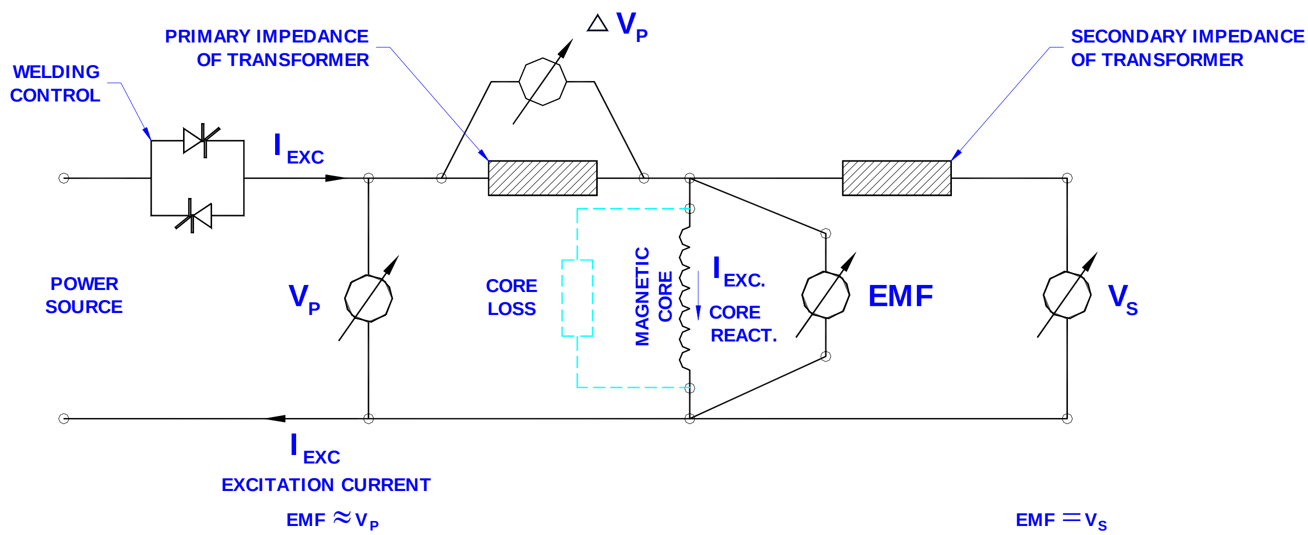


Figure 4.

LOAD

B. ELECTRICAL EQUIVALENT DIAGRAM (BASED ON A 1:1 TURN RATIO)

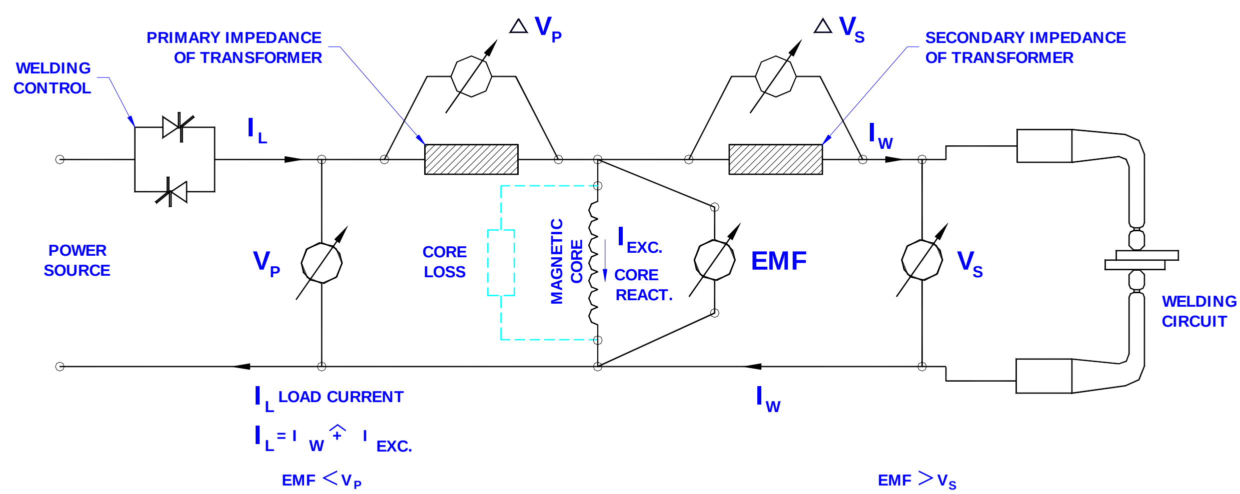


Figure 5.

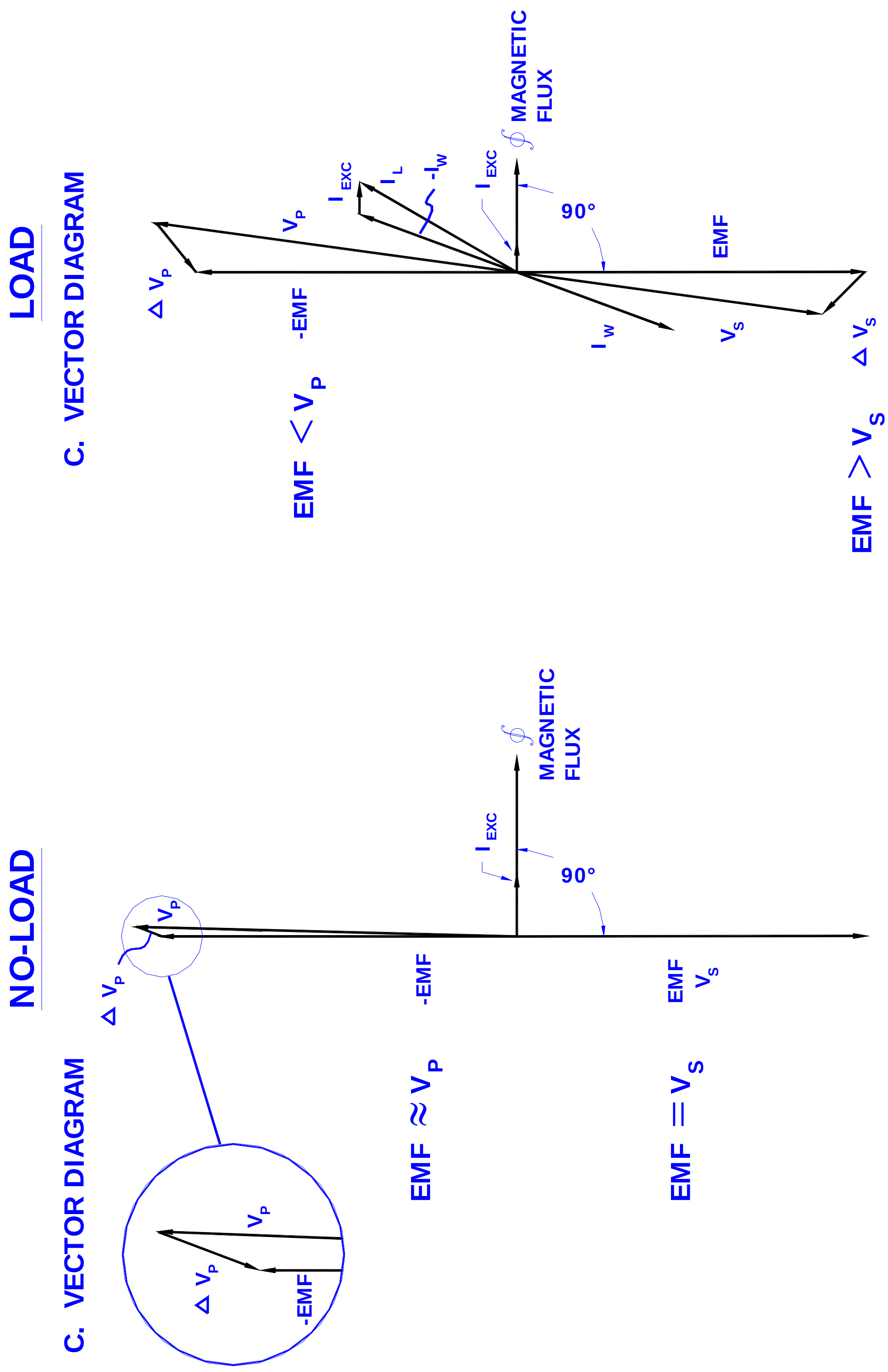

LOAD
C. VECTOR DIAGRAM
EMF < V P
EMF > V S
Δ V P
V P
-EMF
I EXC
I L
-I W
I EXC
MAGNETIC FLUX
90°
EMF
I W
V S
Δ V S
NO-LOAD
C. VECTOR DIAGRAM
EMF ≈ V P
EMF = V S
Δ V P
V P
-EMF
EMF
V S
I EXC
MAGNETIC FLUX
90°

Figure 6.

RESULTS OF RESEARCH

As stated in the background section, the transformers used for this investigation were as follows: (See Appendix A for Drawing)

Transformer Design	Optimized	Original	Optimized	Original
KVA AT 50% (RATED)	93	65	136	90
PRIMARY VOLTAGE	480V/60HZ		480V/60HZ	
SEC. VOLTAGE [V]	10.9		16	
SECOND. ECTC [A]	6000	4200	6000	4000
TURNS RATIO	44:1		30:1	
KVA AT 50% (TESTED)	105	---	140	---
SEC. ECTC (TESTED) [A]	6800	---	6200	---
FLUX DENS. [G]	23,100	19,100	23,300	19,300
FRAME SIZE [IN]	5x6.75x16.81		5x6.75x20.81	
WEIGHT [LBS.]	89	85	119	113
SEC. IMPEDANCE [μΩ]	147.2+ j67.5 (Z= 162)	193 + j90.6 (Z= 213)	194 + j77 (Z =208)	241 + j110 (Z = 265)
SEC. SHORT CURRENT [A]	67,300	51,100	76,600	60,400

Note: Thermal test complies with RWMA Bulletin 16.

Chart 1

Chart 1 shows that significant gains were made in the thermal rating of the 5” x 6 ¾” frame transgun transformer. It is important to note that the physical dimensions of the transformer did not change. This allows removal of a 65 KVA transformer from a transgun assembly and replacing it with a 93 KVA transformer that has higher short circuit current and much-improved thermal characteristics. Several other important factors can be observed in Chart 1. The test shows that the secondary ECTC (Equivalent Continuous Thermal Current) on the 93 KVA was 6800 Amps and on the 136 KVA it was 6200 Amps. The decrease of the ECTC value by 600 Amperes experienced on the 136 KVA transformer is due to the longer mean length of its primary and secondary winding. The increase in mean length generates higher watt losses in the windings. This, in turn, raises the water temperature between the in and out port of the water circuit when compared to the 93 KVA transformer. The increase in water temperature detracts from the overall thermal performance of the transformer. This also indicates how critical water flow is. The tests were performed with one gallon per minute water flow, not exceeding 30 degrees Celsius incoming water temperature. Increasing the flow beyond one gallon will improve the thermal rating.

An added benefit of increasing the copper volume in the primary and secondary is a reduction in impedance. This allows for higher short circuit currents, which translates into higher welding current from the same size transformer. When looking at welding performance, the critical parameter that is affected by improved thermal characteristic is the number of welds per minute at a given welded current. Chart 2 and 3 show a comparison between the 65 KVA and 93 KVA and the 90 KVA and 136 KVA transformers respectively.

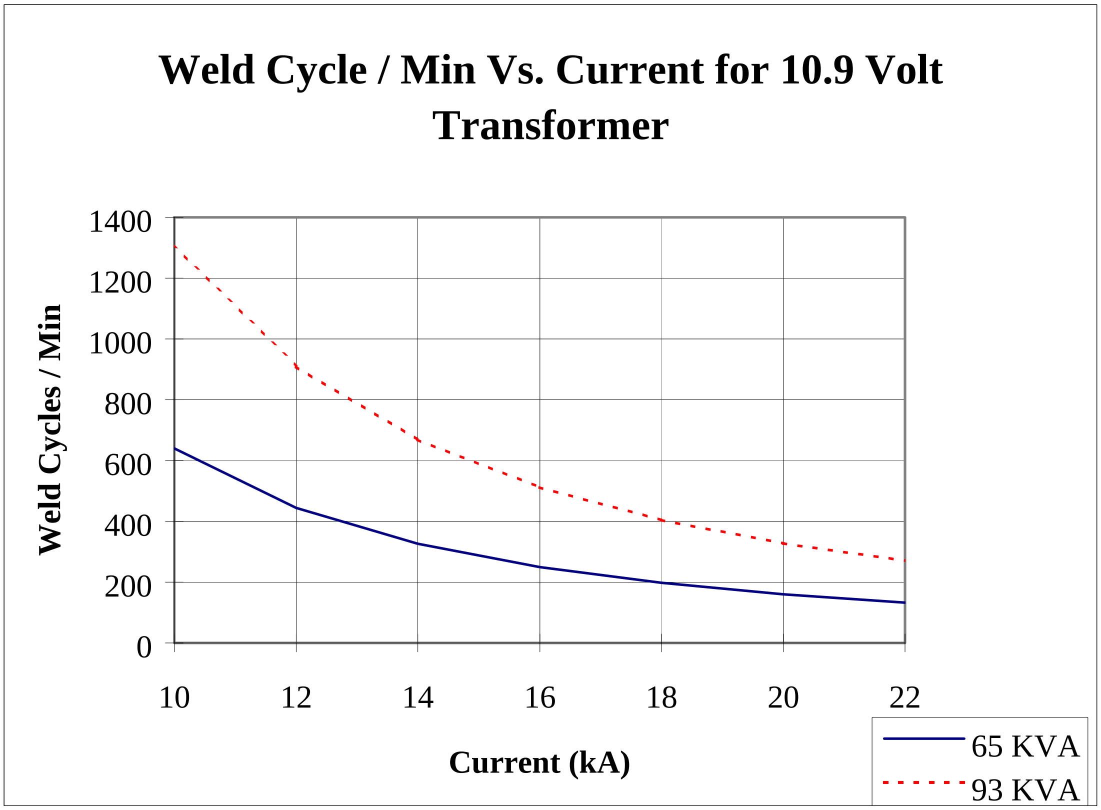


Chart 2

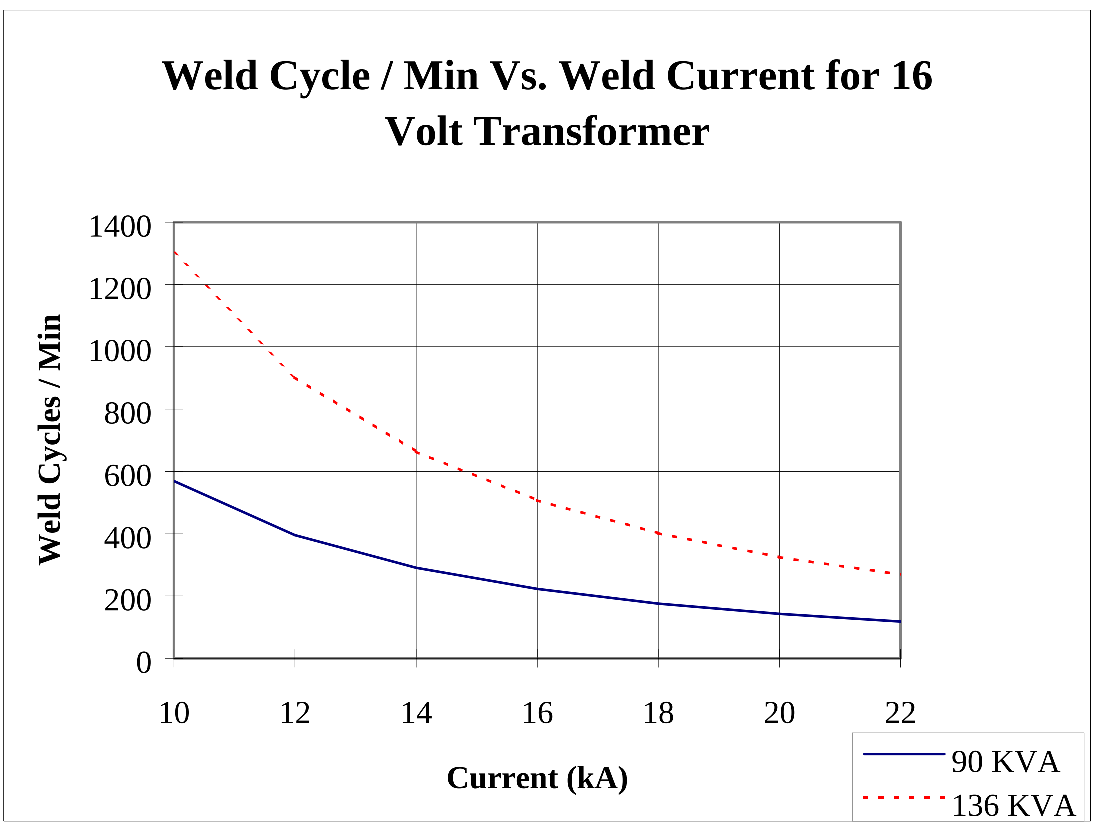


Chart 3

As shown in Charts 2 and 3, the number of weld cycles allowable per minute was greatly improved. Charts 4, 5, 6, and 7 show the increase in the number of welds per minute at given weld times.

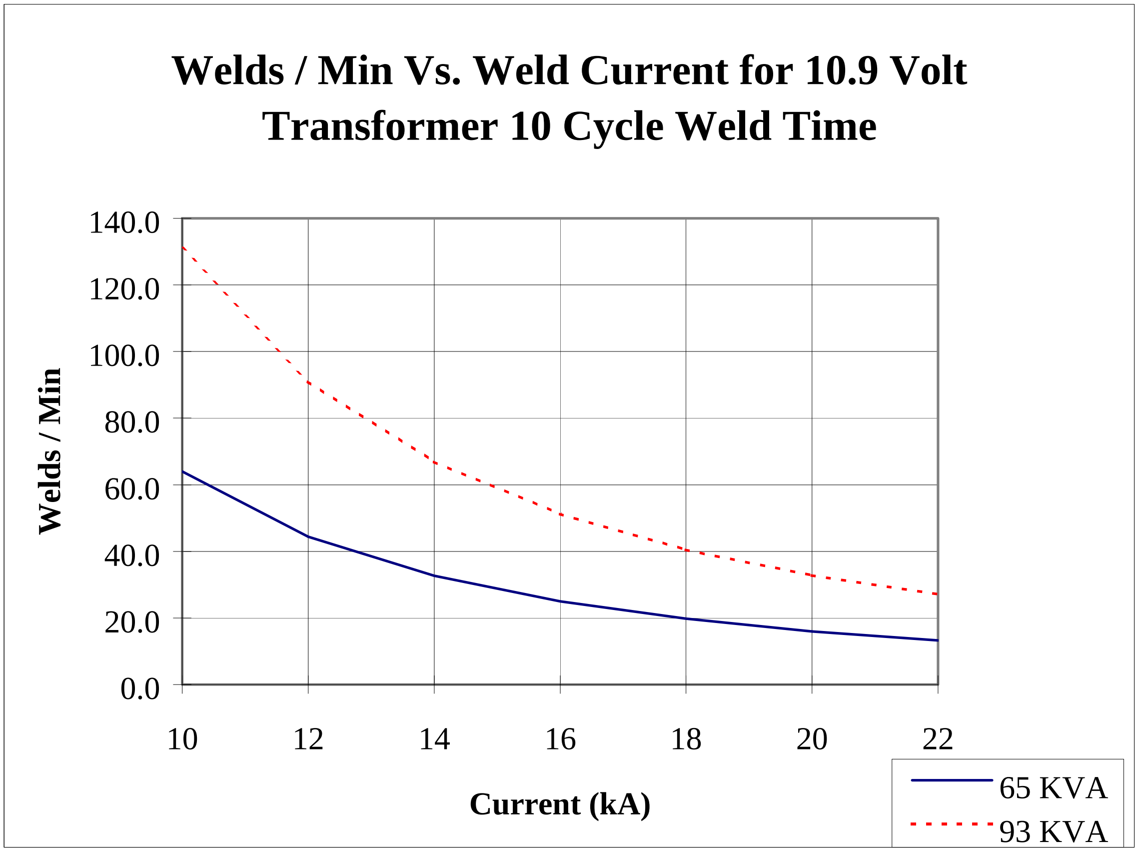


Chart 4

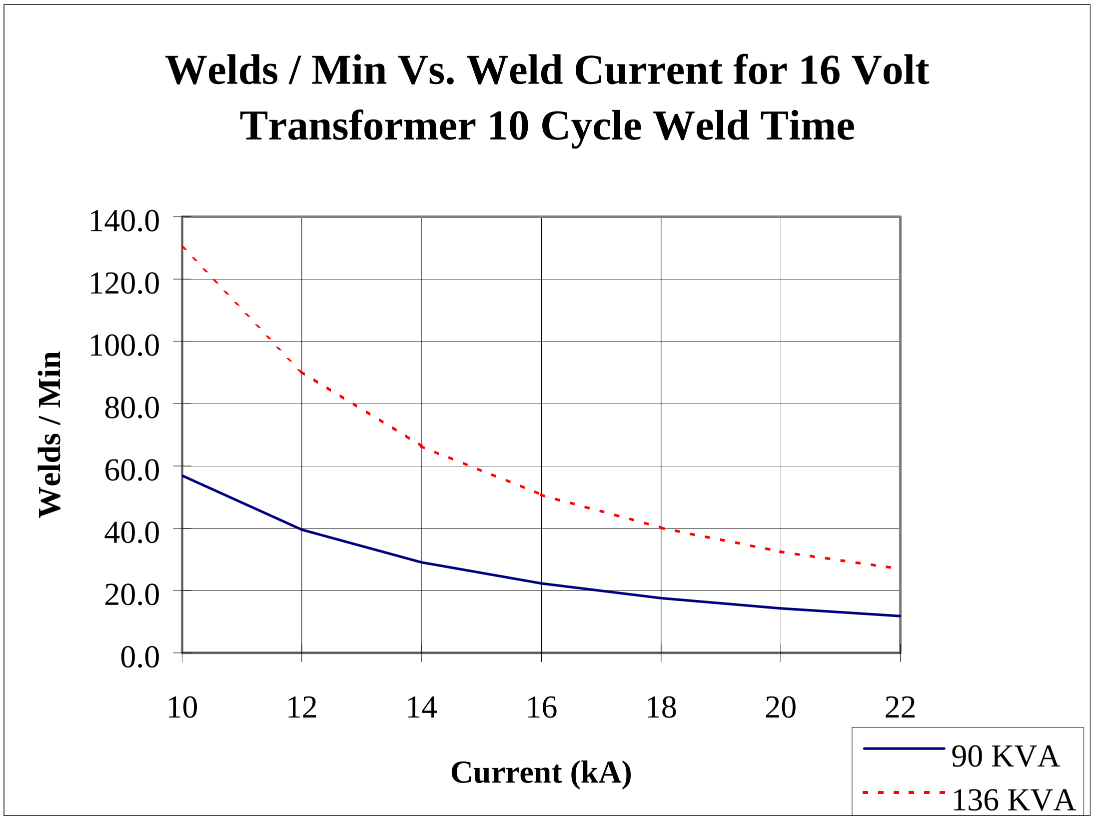


Chart 5

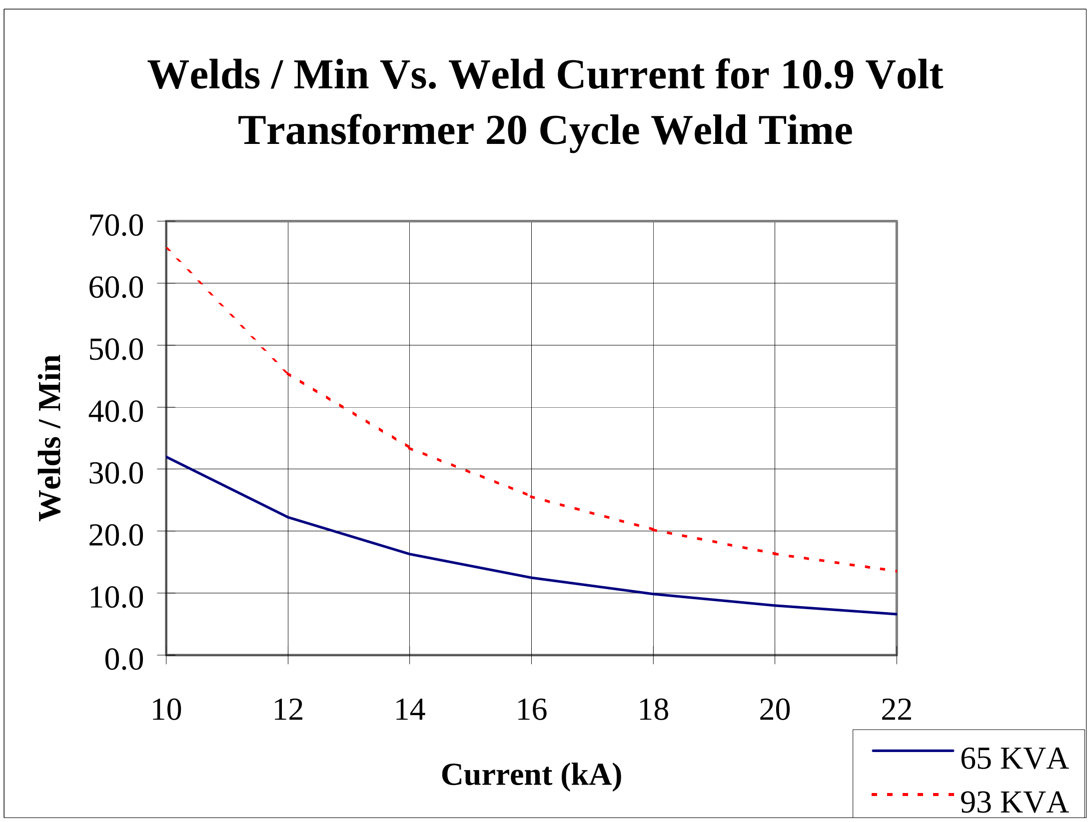


Chart 6

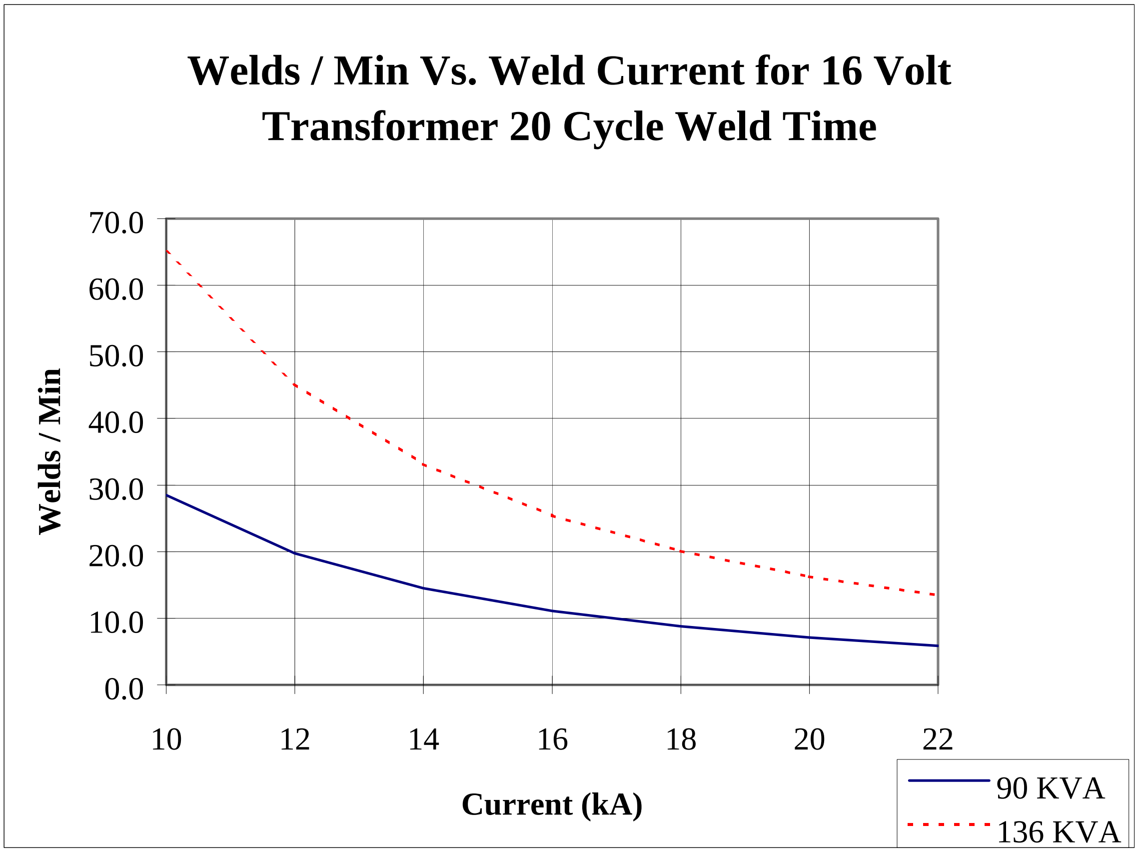


Chart 7

As with all improvements, there are some concerns. As noted in the transformer construction section, the high-flux density style transformers should never be fired with an open secondary. This could result in very high primary currents that flow through the weld control and will affect the accuracy of current monitoring via the primary. Water flow becomes very important in the high thermal style transformers.

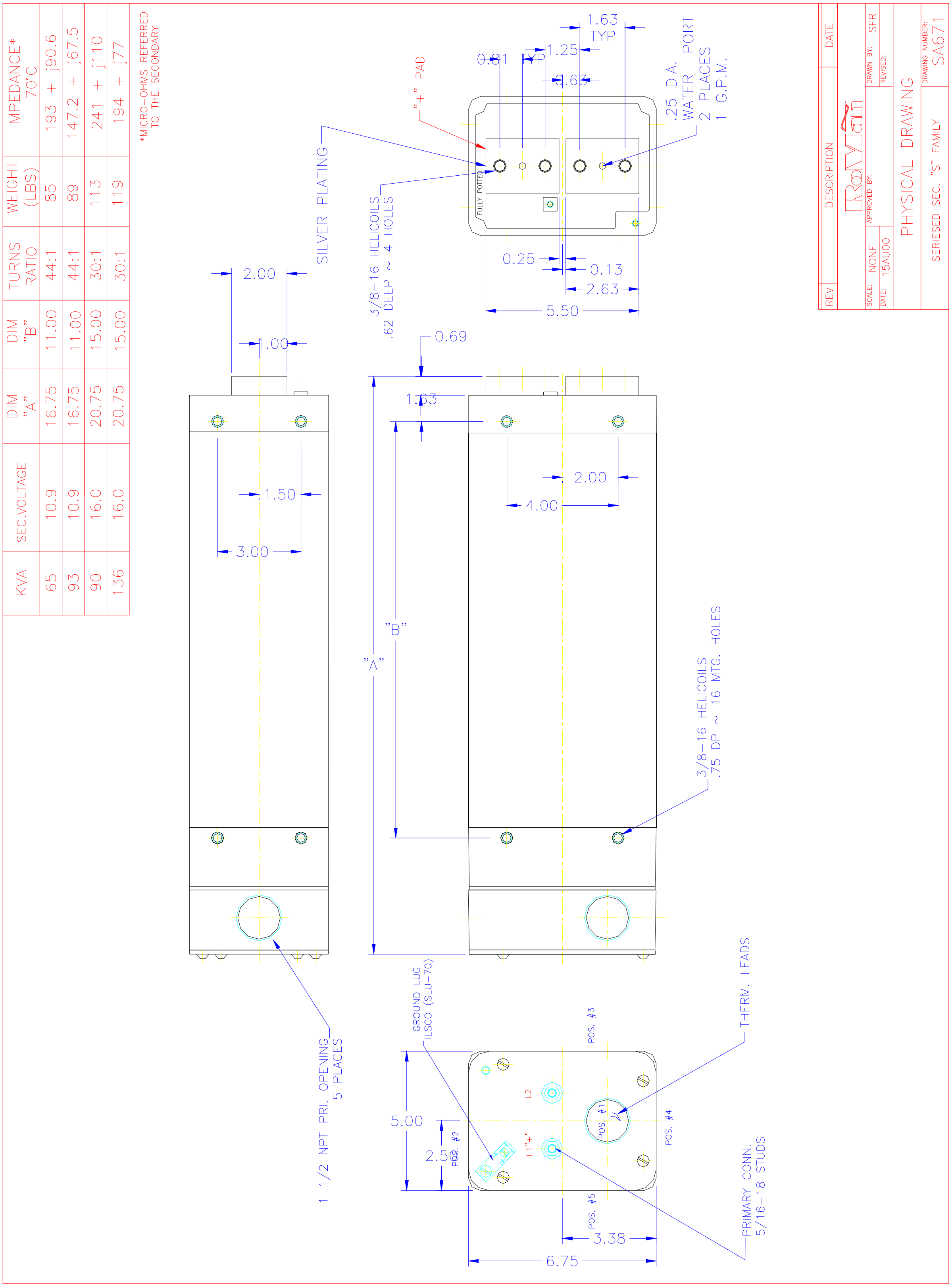
Unrelated to the transformer, another important consideration is what affect does the high KVA have on the associated equipment. After all, the transformer is a link in a chain and by making that link stronger, it does not necessarily make the entire chain stronger. More specifically, the secondary shunts and gun components must be able to handle the 6000 Amp ECTC. Also, the primary conductors and quick disconnect plugs must be robust enough to handle the higher rated primary currents that come with the high thermal rated transformers.

CONCLUSION

The change in the process of welding vehicles has created a demand for transgun transformers that have high secondary voltages and high thermal ratings while meeting the physical size of existing North American standards.

Through extensive research and lengthy testing, this paper shows that a transgun transformer can be designed and manufactured with high thermal ratings in the same physical package that exists in North American automotive plants. This optimization of thermal characteristics comes with the cost of higher flux density than what was previously used and requirements that the associated equipment be robust enough to withstand the demand of higher continuous currents.

APPENDIX A.



KVA	SEC.VOLTAGE	DIM "A"	DIM "B"	TURNS RATIO	WEIGHT (LBS)	IMPEDANCE* 70°C
65	10.9	16.75	11.00	44:1	85	193 + j90.6
93	10.9	16.75	11.00	44:1	89	147.2 + j67.5
90	16.0	20.75	15.00	30:1	113	241 + j110
136	16.0	20.75	15.00	30:1	119	194 + j77

*MICRO-OHMS REFERRED TO THE SECONDARY

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