

**An Overview on the Past 50 Years of Nonvacuum Electron Beam Welding,**  
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## Introduction

The nonvacuum electron beam welding process has been used to do commercial joining applications for upwards of five decades now, and over this more than 50 year time span has repeatedly shown itself to be a highly rugged and reliable production tool. The present primary concept of utilizing a differentially pumped, multi-stage vacuum method as means for both generating the beam under high-vacuum conditions and transmitting it out into the atmosphere was initially proposed in 1953 [Ref. 1] – and then subsequently demonstrated in 1954, in Germany, when such a configuration was first used to produce a 4kW nonvacuum EB welding device. Since that time the experience gained from an ever increasing usage of the process has contributed to allowing today's manufacturers of nonvacuum EBW units to provide equipment with the capacity for demonstrating a much higher degree of both functional capability and operating flexibility – while simultaneously providing users of the process with steadily decreasing operating costs to contend with.

In nonvacuum electron beam welding (NVEBW), which was initially called both “atmospheric electron beam” (AEB) welding and “workpiece out of vacuum” (WPOV) electron beam welding, a high energy stream of electrons produced under vacuum is employed to bombard a target located under atmospheric conditions. This ability to apply an electron beam directly in atmosphere, rather than having to place the target the beam is to be impinged upon in some form of vacuum environment (as is required with vacuum EB processing) greatly enhances not only the EB process' capacity for satisfying applications demanding very high-volume production rates – but also its capability for being able to better address welding of large size and 3D-shaped parts. Consequently, during the past five decades the NVEBW process has been successfully employed to perform a broad range of both varying size and shape, high-volume production joining tasks.

Initial efforts at utilizing the NVEBW process for accomplishing high-volume part-throughput type applications were directed at continuously welding tubing at very high speeds. Thus, by the mid-1960's, PTR (who, with its predecessors HSD & L-HVS, has been in the nonvacuum EB welding business since the early 1960's) began supplying a number of NVEBW units for marriage with tube mills. These units were used to produce a variety of tubular products by doing the closure seam weld on tubing that was being continuously formed out of flat strip at speeds with values approaching 100FPM, when doing comparatively thin wall type tubing, speeds much faster than were achievable with more conventional joining methods being employed at that time. Then, toward the late 1960's, the process was adopted for use in seam welding discrete tube sections for the automotive industry – steering column “jackets” (i.e., the outer tube portion of the SSG collapsible steering column assembly). For this application a carousel style tooling

package (i.e., a “merry-go-round” type of part transfer unit) was utilized for cyclically passing these tubular segments under the beam – and for providing the capacity to produce in the range of 600 to 800 welded tubes per hour off of each of the three NVEBW systems initially supplied for doing this particular joining task, a total hourly part-production capability of from 1,800 to 2,400PPH. It was at this point in time, then – starting in the late 1960’s, that the process began to be widely accepted by the automotive industry for producing a broad range of varying size, shape and material composition components for use in both passenger and heavy-duty (truck & bus) style vehicles [Refs. 2 – 4].

## Process Description

A differentially pumped nonvacuum EBW gun/column assembly consists of a high-vacuum beam generation section, where a triode style electron gun is used to generate the beam, and a series of separately pumped vacuum stages that provide the beam a graded vacuum-to-atmospheric pressure path to travel in. Thus, after generation, the beam travels down through a series of increasing pressure stages, connected in tandem by a set of concentrically aligned orifices, and out into the surrounding atmosphere. Electromagnetic focusing and deflection coils, positioned along the beam’s travel path, help ensure the beam passes cleanly through this series of orifices while making its journey from high vacuum to atmospheric pressure.

Although some random collisions will occur between electrons in the beam and any residual gas molecules the beam might encounter during its passage down through the column, these collisions cause the electrons to incur little (if any) energy loss or deviation in travel path direction. Thus greater than 90% of the beam power being generated by the electron gun is delivered out into the atmosphere; consequently, the OVERALL (total “wallplug-to-workpiece”) energy conversion efficiency capability of a nonvacuum EBW system generally exceeds 60% - a value equal to or greater than most conventional welding means, and much greater than various other power beam joining methods.

Once the beam exits the last column orifice and enters the surrounding region, however, the frequency of collisions between beam electrons and ambient-atmosphere gas molecules will increase significantly. Although these collisions don’t greatly impact the energy of the beam electrons they do cause them to gradually be dispersed; this, then, causes the beam diameter to increase - and thus the beam power density to decrease, the greater the distance the beam travels out into the ambient atmosphere. In order to help reduce the effect of this normal beam scattering occurrence a helium-blowdown style exit orifice may be utilized; this style of exit orifice provides a helium effluent which exits the orifice coaxial with the beam. As such, it provides a lower (than ambient) density gas channel for the beam to temporarily travel in – thereby allowing a greater “standoff distance” (i.e., the distance measured from the bottom of exit orifice to the top of workpiece) to be achieved than would normally be possible. The present day, differentially pumped NVEBW gun/column assembly has been designed to operate

mounted in any attitude (from vertical to horizontal), be capable of travel motion during operation, and to perform reliably under adverse conditions – as well as for being easy to maintain.

### **Examples of NVEBW's Broad Range of Application**

The steering column jacket units previously described were immediately followed by two other nonvacuum EBW high-volume production automotive applications, the AO Smith "blank welder" units described in Ref. 2 and the GM Powertrain Div. torque converter welder units described in Refs. 3 & 4. The later of these two applications resulted in some 20 NVEBW systems being put into production, during the period covering 1970 to 1995, to do this task alone - and a number of these units are still being utilized in production today [Ref. 5].

As outlined in Ref. 2, during the mid-1900's AO Smith initiated using EBW for one of the earliest tailored blank applications noted – joining contoured segments of low carbon steel into a single, finished-shape blank which would then be deep-drawn into a complex, three-dimensionally shaped configuration used for fabricating car frame sections. The employment of this method of producing the final contour-shaped blank needed for this task resulted from the fact that a more efficient utilization of raw material could be achieved by stamping out shorter contoured segments and then joining these together to form the final, full-length contoured blank section required; this, then, helped reduce the cost associated with producing these final blanks. Components being welded ranged from roughly 1/8 to 3/16 inch in thickness, and could be joined using weld speeds on the order of 200ipm. Parts were passed under the NVEBW column (located inside of safety enclosure) utilizing a conveyor-style of tooling arrangement that continuously transported parts through the weld zone, allowing up to 800PPH to be achieved off each of the two NVEBW systems being employed for this joining task. Because of the slight broadening effect the beam incurs when traversing the distance between exit orifice and workpiece, the process proved to be readily able to easily weld the "as sheared" butting edges on the part segments being presented to it for joining – thus additionally saving on the cost that would have resulted if a post-shear preparation of these edges had been required prior to welding.

As described in Refs. 3 & 4, GM Powertrain's Hydra-Matic Div. started utilizing the NVEBW process for doing the final hermetic-seal weld required on torque converter assemblies back in the late 1960's/early 1970's. The initial system design involved using an inline, manually feed part transfer scheme for getting parts in/out of area where welding was performed – and was primarily operator paced, production wise. Later systems supplied, however, employed a multi-station dial index form of part transport scheme with auto load/unload features for transferring parts thru the weld area; this allowed total floor-to-floor cycle times of 13 to 15 seconds (depending on whether a 9.75" or 11.5" converters were being welded) to readily be achieved – resulting in production rates in the range of 235 to 275PPH being consistently attained from each

the numerous system's supplied between 1975 and 1995. When the NVEBW process was initially employed for doing this task the torque converter assembly's cover and body segments were quality stamping type parts produced out of aluminum killed steel – and very conducive for being able to directly accomplishing a hermetic-seal weld on; with time, however, material and part tolerance quality decreased due to cost reduction efforts. Consequently, it became necessary to equip each system supplied with wire feeder capability - in order to provide the combined capacity for simultaneously adding a filler and de-oxidizer material; this, then, helped ensure a hermetic-seal weld could be accomplished on every part welded, regardless of the part material content and/or part seam fit-up conditions being supplied.

As additionally described in Refs. 3 & 4, with the advent of CNC motion control capability in the 1970's the process began to be adapted for doing components having relatively complex, 3-D shaped weld paths – such as the die cast aluminum intake manifold assemblies (the 4, 6 and 8 barrel versions) it was utilized for joining. As indicated in Refs. 3 & 4, this application was a prime example of using the process not only to accomplish welding of a part having both a specialized weld joint geometry and complex seam path – but also one simultaneously involving components formed from a difficult to weld material. The NVEBW process, however, was not only able to overcome all these various challenges - but was also able to be successfully employed to consistently weld these manifold assemblies, in production, at weld speeds in the range of 200 to 400ipm.

Another example of a difficult-to-weld task successfully accomplished using NVEBW is also described in Refs. 3 & 4; this is the catalytic converter assemblies that were welded using the nonvacuum EBW process. Here four layers of 0.050 inch thick steel had to be welded in a horizontal attitude to produce a hermetically-sealed edge weld – both reliably and repeatedly in production, and at weld speeds on the order of 300ipm. The some 17 systems that were put into operation for doing this task during the late '70's and early '80's provided the capacity for supplying the automotive industry with upwards of 7,000,000 nonvacuum EB welded catalytic converters annually .

## **Conclusion**

As expressed by this presentation, since being introduced to industry some 50 years ago the nonvacuum EBW process has been employed for welding a fairly large variety of high-volume production components for the automotive industry, worldwide. Initially starting out as being used only for doing fairly simple type linear welds the process eventually evolved to the point where it could standardly be used for performing highly complex, 3-dimensional type welds. Thus the process has, over the past 5 decades, clearly demonstrated it's inherent capacity for readily adapting to the broad range of both workpiece conditions and operating environments generally associated with this area of industrial application. In addition, in more recent years,

the process has also shown itself to be fully capable of successfully accomplishing applications that not only involve unique materials but also necessitate that tight after-weld dimensional tolerances be strictly adhered to [Refs. 6 & 7].

## References

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