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# IMPROVING THE WAVE SOLDERING PROCESS WITH NEW NITROGEN RETROFIT SYSTEMS

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## Abstract

Despite the predicted demise of the wave soldering process, this soldering technique continues to be widely used. The use of connectors and the overall cost effectiveness of the process maintain its viability. As the pressure to reduce cost and improve quality increases in electronic manufacturing, assemblers using wave soldering must consider all innovations if they want to meet these challenges created by intensified competition. One option is to adopt an inert soldering process. This process is not new but recently it has evolved significantly. New, simple and optimized inerting systems which simplify converting to nitrogen are now available. Additionally, the cost of such devices combined with the overall lower cost of inerting <sup>[1]</sup>, make it opportune for the individual assembler to evaluate retrofitting the existing wave soldering equipment to allow for nitrogen inertion.

This paper describes the implementation of such a nitrogen retrofit system at a high-volume, mixed-assembly plant where communications systems and products are manufactured. It discusses the motivation and objectives of this PCB assembly facility to convert to a nitrogen process. The retrofit system selected is described and its implementation is detailed. Technical results and benefits are reviewed and analyzed. Finally, the cost vs. benefits analysis is presented. It is demonstrated that with this particular retrofit device, the implementation of nitrogen has both qualitative and economic advantages.

## Introduction

Although many industry roadmaps call for an elimination of the wave soldering process, this technique continues to find its niche. New packaging technologies are evolving toward smaller and more powerful devices, but a demand still exists for pin-through-hole components and bottom-side SMT devices. The mechanical strength required by connectors as well as the lower cost of wave or flow soldering make it a widespread and viable process. Moreover, many products still do not require the functionality of SMD components, so the additional cost and investment for SMD is not justified. The process itself has seen many innovations, which have dramatically improved on the old method. These innovations include spray fluxing, convective pre-heating, as well as the introduction of nitrogen or inert atmosphere. Current R&D is evaluating even the elimination of flux in this process.

Use of nitrogen within inert soldering systems during the assembly of PCBs continues to increase worldwide both in wave and reflow soldering operations. But while the use of nitrogen in reflow operations is often debated because the benefits are process specific and more difficult to quantify (quality based), there seems to be little doubt in the mind of the user that nitrogen improves the wave soldering process. By reducing oxidation and increasing surface tension, stronger bonds and faster wetting are obtained. This results in quality

improvements and defect reduction. The solder joint strength is increased, which translates into higher reliability. The gross production is also reduced, which spells out solder savings, environmental, health, and even production benefits.

Despite the overall attractiveness, many potential users have not adopted a nitrogen process in wave soldering. One reason is the substantial capital investment required for a 'nitrogen-capable' upgrade if this option is available at all. Specific patent restrictions have prevented some equipment manufacturers from offering this option, which has obviously affected the price of such devices. There is also the aspect of popularity: only equipment vendors with a good N<sub>2</sub> solution promote controlled atmosphere soldering. In other instances, the failure of some existing designs of nitrogen equipment (cover & curtains, tunnel based) to meet the needs of many soldering operations has eliminated any potential for nitrogen adoptions. Additionally, a couple of years ago the 'cost vs. benefit' situation of nitrogen in wave soldering was still unclear and did not justify, at that time, the extra capital expense for such equipment. Finally, the energy and funds required to purchase a retrofit kit, when available, presented a significant obstacle.

However, the viability of wave soldering as well as specific needs in inerting technology have led to the development of new inerting expertise. As a result, simple and effective options exist both in new equipment and as retrofit solutions. Additionally, because the overall cost of inerting is much lower with these new devices, the assembler may now take the opportunity to evaluate whether he can improve quality and reduce the cost of his process by inerting. And because the vast majority of the existing wave soldering machines are not N<sub>2</sub> capable, the idea of retrofitting makes sense.

## **Motivation to Adopt a Nitrogen Process**

The implementation was performed at a plant where telephone switches, calling centers and other telecommunication products are manufactured for the world market. The plant is equipped with numerous SMT assembly lines. In addition, the facility has two wave soldering machines; a fully inerted tunnel machine and a conventional high-volume wave soldering machine. The latter was manufactured by Streckfuss, a German supplier of soldering equipment and installed on line B/C. The plant employs more than 1600 people. Thanks to a booming demand for communications products, the plant operates with three shifts on a five day-week.

Like other electronics products, the demand for communications products is growing significantly around the world. At the same time, intense competition, particularly in America and Asia, continues to drive down the price for such products. Faster time-to-market and manufacturing cost reduction pose real challenges. For some assemblers, one of the methods to achieve such objectives is to innovate. Any innovation that can meet certain cost and cycle time conditions is studied seriously. So, when a new nitrogen retrofit system was offered to this assembler, it was decided to evaluate such a system on the Streckfuss machine - line B/C. The intention was to adopt such a system permanently, if its benefits would support shorter time to market and process cost reduction objectives.

One of the specific objectives for this particular assembler was to improve uptime of their assembly line. Because of gross production, the machine needed to be cleaned and maintained frequently. This process, in addition to being labor costly, is disliked by machine

operators. It is a process disturbance that prevents 2-3 hours of production time per day. Other goals were to reduce the losses associated with dross production, improve yield and reduce touch-ups. It was expected that switching to an inerted process would allow the opening of the process window of the current low solids/no-clean process. Additionally, an increase in reliability of the assembly would be another benefit. The expectations were based on current results obtained with the second machine, which was purchased nitrogen-capable and which is operated under inert gas atmosphere (tunnel machine).

## **New Nitrogen Retrofit Technology**

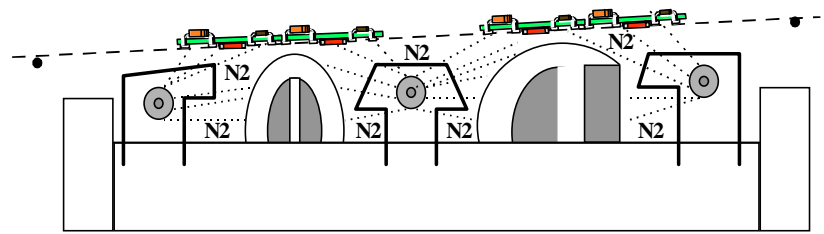
The retrofit system selected is of the 'blanket-type', a technology introduced several years ago. The benefits of this wave soldering inerting method over other inerting systems have been detailed by many users<sup>[2]</sup>. Inert boundary technology inertes the solder pot by means of a 'blanket' of nitrogen gas bled at the printed circuit board / solder wave interface. When the PCB reaches the waves, nitrogen is trapped between PCB and the solder; thus, the assembly literally acts as a cover over the waves. In the fraction of a second the atmosphere at the bottom of the board sees an oxygen content of less than 10 PPM, which is in the same order as the quality of the nitrogen source. This system operates in an open environment and does not require any enclosure or curtains to maintain an inert atmosphere. The unrestricted access to the waves eliminates any possible mechanical limitations.

Like other nitrogen systems, the system commissioned is comprised of a gas distribution panel, an injection assembly and flexible tubing that link the two. The gas panel regulates nitrogen from the nitrogen plant distribution network and distributes it to the injection assembly. This system, however, features significant variances to other inert boundary systems. The injection assembly consists of three porous sintered diffusers that are enclosed in a titanium frame—the plenums. The plenums are attached to each other with side plates, which transform the system into a complete one-piece assembly (Figure 1). This construction serves several purposes. It contains the diffusers, directs a laminar flow of nitrogen over the waves and maintains the assembly in position while preventing air ingress from the side of the pot. Specially designed slits on each plenum of the system allow a uniform, localized inerting of the waves. This method gives the gas velocity and optimizes injection. In addition, it prevents flux vapors from clogging the nitrogen diffusers. The wave chute areas, critical for dross production because of the agitation of the molten solder, are constantly inerted by this design so that the production of dross is dramatically reduced. The whole assembly fits between the solder wave nozzles (Figure 2).

The key feature of this technology is its method of injection. The slight pressurization of nitrogen and its guided diffusion through the slits in the plenum, allow the installation of this system over any type of wave(s). Therefore, the installation does not require any nozzle changes or modification. This feature allows the user to equip or retrofit virtually any brand and model of flow soldering equipment.



**Figure 1:** Injection Assembly



**Figure 2:** Schematic of the Injection Method

## Implementation

The design of wave soldering equipment differs greatly from one manufacturer to the other. Furthermore, the solder pot and nozzle configuration are often different between models of the same manufacturer because end users select different options. Hence, due to the boundary wave design of any particular machine, the retrofit needs to be customized to fit any selected equipment. This ensures that each diffuser is optimized and adapted to a particular machine operation.

After a pre-evaluation of the soldering pot, a measurement session was organized. This meeting enabled the manufacturer to take the precise dimensions of the solder pot and solder nozzles from which to prepare the drawings for the nitrogen system, and to plan the installation. One nitrogen system technician performed this task with the assistance of one machine operator. The machine technician was present to facilitate the manipulations and to ensure safety. After the machine was stopped, the solder pot was pulled out and both nozzles were removed and cleaned in order to expedite the process. Both the angle of the conveyor as well as the wave height were measured. The future location of the gas cabinet was determined. This particular machine was equipped with a conventional turbulent and a laminar wave. To make things more interesting, the nozzles exhibit a 70° angle with respect to the conveyor travel. This feature is to reduce the formation of bridges. After the operator performed the cleanup of the pot and the assembly, the nozzles were reinstalled and the machine was put back into production. The whole process took two hours and was performed during a slowdown in production.

The actual installation took place a month later. Mounting consisted of fitting the system assembly over the solder pot and nozzles, securing it to the nozzles and the solder pot, installing the gas panel, and hooking up the flexible hoses and quick-connectors between the gas panel and the system assembly. One technician took four hours for this entire hook-up, a time which also included a partial cleanup of the machine by the operator.

## Process Adjustments and Operating Conditions

All wave machine parameters were reviewed prior to the commissioning of the nitrogen process. Parameters such as wave height and flux quantity, particularly influenced by a nitrogen atmosphere, were closely monitored. Boards are of various dimensions and generally FR-4 with HASL or Ni/Au finish, single or double-sided. OSP is now starting to be used. The solder material used is low-drossing Sn63Pb37.

### ***Flux Adjustments***

The choice of flux directly impacts solderability issues as well as the resulting cleanliness of the assembly after soldering. As an innovative measure to improve the process, the assembler switched to a low solids flux a year before inerting. The foam fluxer was replaced with a spray fluxer and the flux medium changed from 20% to 2% solids. Benefits were immediate: increased SIR values, savings in flux and alcohol, reduced handling and storage of alcohol, as well as greatly reduced VOC emissions. This change, however, contributed to a reduction of the 'process window'. Keeping the dpm rate at an acceptable level became more demanding and fine-tuning had to be performed with every new batch of boards and components. Switching to nitrogen was seen as a measure to re-open this 'window'. The fact that the use of nitrogen generally allows the use of milder fluxes (or less flux) than would be tolerable in air was a well-established fact for this manufacturer. Switching to an inert atmosphere could further reduce the flux consumption. Although reducing the flux deposition by a further 25% has been proven successfully, this measure has not been implemented yet. The current deposition rate is quite low at 15 ml/min and lowering it further was not initially a concern.

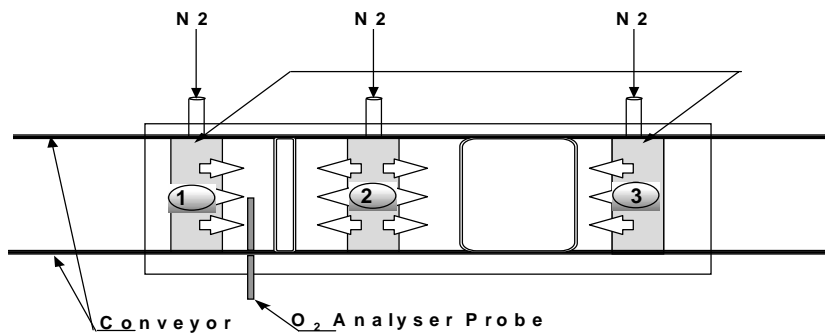
### ***O<sub>2</sub> Level and Nitrogen Consumption***

With an inert boundary system, measuring the oxygen content in parts per million (PPM) is distinct from conventional short-hood or tunnel systems. The PCB is an integral part of the inertion method as it acts as a seal over the waves. When the PCB enters the wave, the volume underneath the PCB is instantly purged with nitrogen injected from the diffusers. Theoretical calculations allow us to estimate that the volume between the wave, the diffuser, the solder pot and the PCB is renewed ten times in one second. Therefore, a low oxygen content atmosphere can be expected at the board / wave interface. However, when there is no board to be soldered, there is no sealing effect and the atmosphere is not as pure. Measurement of the oxygen level therefore greatly varies depending on whether a board is present or not.

The verification of the oxygen PPM level was performed with an oxygen analyzer equipped with a Zirconia cell. Zirconia cell systems have a rapid-rate of response, which is required for frequently alternating measurements. Two set-ups were considered;

- I. A dummy board with drilled holes and attached tubes;
- II. The insertion of a stainless steel tube between the wave and the diffusers, close to the PCB and centered in the middle of the N<sub>2</sub> injection system.

The latter method was selected because it would allow a correct measurement with and without a card (Figure 3). This method could eventually be implemented permanently and allow oxygen monitoring as a quality control measure.



**Figure 3:** Oxygen Measurement Set-Up

The nitrogen flow rate for each diffuser was set from experience with similar processes and fine-tuned to deliver the best O<sub>2</sub> PPM / N<sub>2</sub> flow ratio. Extensive research and experience indicate that the full range of benefits for inert flow soldering systems can be reaped only with an atmosphere of 50 PPM or less<sup>[3]</sup>. In order to reflect process conditions (dross is largely created when the waves run) O<sub>2</sub> values without PCB presence were recorded only when the pumps were running. For reference, the nitrogen is supplied in bulk format and contains generally a maximum of 3 PPM O<sub>2</sub>. Table 1 summarizes the results.

System Type	Area	Diffuser Number	N <sub>2</sub> Flowrate	O <sub>2</sub> PPM w/o PCB	O <sub>2</sub> PPM w/ PCB
Dual Wave System 22"- (55 cm) Nozzles	Front Turbulent Wave	1	252 scfh (7.00 Nm <sup>3</sup> /h)	8000 PPM	7 PPM
	Between Waves	2	288 scfh (8.00 Nm <sup>3</sup> /h)	8500 PPM	10 PPM
	Rear Laminar Wave	3	288 scfh (8.00 Nm <sup>3</sup> /h)	8100 PPM	7 PPM
			828 scfh (23.00 Nm <sup>3</sup> /h)		

**Table 1:** Nitrogen Consumption and Oxygen PPM Content.

It is important to note that the N<sub>2</sub> flow values are flowrate data, not actual hourly consumption. Connecting a solenoid valve with the pump switching system would result in a reduction of the hourly consumption, thus causing nitrogen usage savings. Additionally, when the turbulent wave is not used, Diffuser Number 1 may be turned off. Evidently, one would expect the above nitrogen flow rate data to be lower for nozzles of smaller dimensions as well; there is less to inert.

## Results and Technical Benefits

After six months of operation and thousands of soldered boards, it has been demonstrated that switching from ambient atmosphere to a nitrogen process with the new inert wave soldering retrofit system surpassed the initial objectives. Thus the system has been adopted on a permanent basis.

### ***Dross Formation***

Paramount to the benefits of nitrogen in wave soldering processes is a decrease in the production of dross. Dross is the silvery sludge that covers the surface of the solder pot. It consists mainly of good solder and some tin oxide and maybe some lead oxide. Dross forms when molten solder on the surface of the solder reservoir, or bath, comes in contact with oxygen. A thin film of dross is beneficial because it protects the bath by slowing down oxidation, but a major accumulation is detrimental to the process. Naturally, the use of an inert atmosphere largely eliminates the creation of dross.

After more than 3000 hours of operation, the dross production rate with the retrofit N<sub>2</sub> system has now been established at an average of 0.66 lbs / hour (0.3 kg/ hour). This figure varies somewhat with the production load, the width of the board being soldered and whether the turbulent wave is used. Intermittent stoppage of the wave also has a significant effect. The above figure is a measure by weight of the dross collected from the cleaning process—no 'de-drossing' agent was used. If we compare with the figures established in air under the same average condition, 4.58 lbs / hour (2.08 kg/ hour), we find that dross formation has been reduced by over 85%.

### ***Maintenance and Equipment Uptime***

Maintenance of the solder pot can be very time consuming. Dross must be removed rather frequently in order to ensure proper running of the pumps and good performance of the waves and thus a reproducible soldering process. And when the production is run at three shifts, 24 hours a day, maintenance reduces the uptime of the assembly line. A reduction in dross production will demand less maintenance to be performed and allow a higher production level. Whereas maintenance was performed 4-5 times a day (or 2.0 - 2.5 hours / day) prior to the introduction of nitrogen, it has now been reduced to a once a day / 30 minute procedure, which is significantly less than before the nitrogen start-up. The line sports an impressive gain of two hours of production time per day. In addition, the reduction in maintenance time has provided greater flexibility. The operators can now perform the cleaning operation during production downturn, and the 'urgency' to monitor and clean immediately when problems became visible has disappeared.

As far as the nitrogen system is concerned, its addition over the solder nozzles has not created any maintenance issues. It can be removed and reinstalled rapidly when solder pot cleaning is required. The system itself has not demanded any care or replacement parts even after six months of operation. The three sintered diffusers, the main elements that could prevent the system from performing correctly if plugged by solder or flux, are still functioning like new.

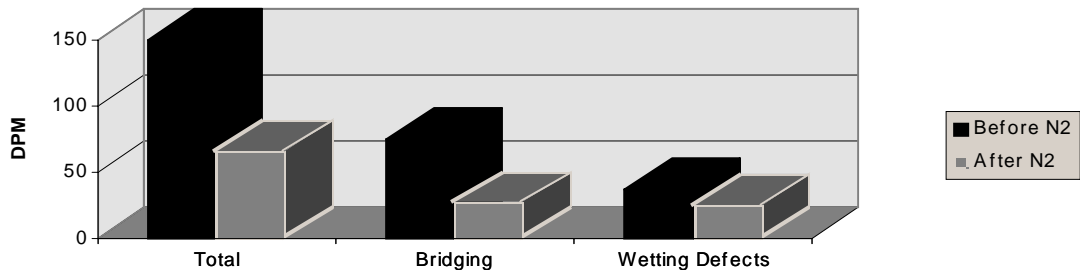
### ***Quality Results and Defect Analysis***

As explained in numerous studies and papers <sup>[2,3]</sup>, soldering under nitrogen modifies two critical parameters that affect the quality of the wave soldering process:

- 1) Nitrogen will eliminate oxidation, which will reduce dross, solder pot maintenance, and increase the wetting force.
- 2) Nitrogen will increase the surface tension on the wave of the molten alloy and increase wetting or the wetting force.

Since dross can induce defects and wetting force is an indicator of the quality and shape of the joints, it was expected that nitrogen would improve the quality of the soldered assembly. Related to this issue is the “increased process window” that everyone is talking about when addressing nitrogen soldering. The process becomes more forgiving under nitrogen than it is in air. The window may be larger, but is it necessary and does it have an effect on reliability and the defect level?

Figure 4 shows the wave soldering process dpm before and after the conversion to nitrogen for a particular ‘problem board’. The general defect level at this PCB assembly facility is low at less than ten dpm. As particularly large sample sizes would be required to verify improvements on that level, a special assembly with some bothersome connector was chosen to demonstrate the effectiveness of this new inerting technology. For this board, the sample data for the ‘before’ and ‘after’ defect levels is representative of a six month period. The dpm number reflects the number of joints that fail inspection (for the joints that are wave soldered only). The operators in the inspection, test, and touch-up areas report every single defect. This recording method represents a process performance check and helps track the quality of the process.



**Figure 4:** Defect Analysis: Before and After Nitrogen (six months period of a ‘problem board’)

With the introduction of nitrogen, the defect dpm rate for this particular assembly has fallen from 150 to below 100 and seems to be hovering around the 60 – 70 dpm level now. A general reduction of about 55% – 60 % has thus been realized. All types of defects have been reduced on this product and thus we may speak of a general benefit that should also transfer to other products and further reduce the already low dpm rates there. The increase in surface tension associated with the use of nitrogen has not translated into more bridging as is feared occasionally. Bridging at the targeted connectors has been significantly reduced, making intervention in the touch-up area less frequent. As bridging materializes in the exit area of the second wave during double wave soldering, the peel-off must have benefited. This may be due to the fact that more flux activity is preserved for this exit area when soldering takes place in nitrogen.

The decline in defects diagnosed as ‘wetting related’ seems to point in the same direction. At the temperatures reached in the wave, nitrogen is an effective way to prevent oxidation of those metal surfaces on the board which must be soldered. Hence, flux activity is not exhausted by actions on metal oxides that would be created in air during this final heating event. A thinner layer of oxides requires less flux activity and hence the flux can a) promote wetting more effectively, and b) reduce surface tension in the exit area of the wave.

Although N<sub>2</sub> may marginally contribute to solder balling in wave soldering applications, this factor has not been observed here. It is believed that the quality of the solder mask and the flux is compatible with inert wave soldering. An explanation of this phenomenon and solutions is detailed in a paper by Triennes et al. [4].

Major benefits were noted in the bed of nails testing area. The incidence of failure of the needle-test itself has decreased considerably. Human intervention has been reduced here too. It is well known that due to the good insulation quality of rosin (colophony) contacting the test points depends on the amount of such deposits. In addition, the stickiness of rosin further contributes to fouling of the needles, making regular cleaning a necessity. Lower solids content combined with a reduction of the deposition rate (spray fluxing) are the primary measures to overcome this problem. In addition, certain fluxes show further improvements under nitrogen. This is generally attributed to a lack of oxidation of flux components under inerted conditions. A direct influence of nitrogen vs. air for the benefit of this test is assumed here as well, but so far has not been documented. Nevertheless, some studies [5] indicate that nitrogen reduces residues for some fluxes compared to their application in air.

Overall and in this particular case, the quality results for the converted 'blanket-type' inerted machine are identical when compared with the fully inerted machine.

### **Economical Considerations**

In addition to allowing a greater production uptime, nitrogen and the new nitrogen retrofit system have reduced the cost of the operation at line B/C. Calculating the cost vs. benefits goes far beyond the cost of the nitrogen. Based on the current results, the cost and savings breakdown is as follows:

**Costs of Retrofit System and Gas:**

Total Cost:	
Nitrogen retrofit system & cost of N <sub>2</sub> per hour:	\$ 3.50 / hour

**Savings Realized:**

Dross reduction	\$ 8.00 / hour
Maintenance labor reduction	\$ 2.00 / hour

<b>Net Savings (Measured):</b>	<b>\$ 6.50 / hour</b>
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**Other Savings & Benefits:**

Higher line uptime	Significant
Repair / Rework reduction	\$ under review
Flux reduction (spray, air vs. N <sub>2</sub> )	25% - future
Fewer residues on the board	
Environmental	

With over 6000 hours of production per year, the net savings realized by converting the process to nitrogen with the new retrofit kit amount to \$ 40,000 / year for line B/C. Considering the hourly costs per line for large modern assembly facilities, the savings become much higher when the uptime and rework reduction benefits are added. These figures apply to the wave soldering process only.

Due to the success in flow soldering with nitrogen, it is planned to gradually expand inert soldering to the reflow process. Although preliminary results are positive, the recent conversion of some reflow processes to nitrogen, caused by the introduction of OSP and new packages, has not yet been quantified.

## **Conclusion**

The conversion of existing flow soldering equipment to nitrogen is now simpler and more convenient thanks to new and optimized retrofit devices. It can bring significant value to the assembler who performs wave soldering and wishes to improve the process.

The goal of a particular assembler to use its experience in nitrogen technology to tackle particular problems in an existing flow soldering line without prior inertion has been very successful. Their choice of a 'blanket-type' diffusion system that could be retrofitted proved to be optimal even in such a demanding situation as the 70° nozzle angle. The retrofit procedure required only minimal interruption, a prerequisite due to the tight production schedule.

Inertion in the critical zone between assembly and solder waves has been excellent. Solder defects have declined significantly. The quality of the inerted area led to quality results that are similar to those obtained with a full tunnel N<sub>2</sub> machine.

The decrease in gross production caused a general decline in maintenance—an activity that was not enjoyed by the operator thus leading to greater job satisfaction. The lower maintenance time translated into a major gain in availability of the production line; on a yearly basis nearly 500 additional hours were freed for production.

Cost calculations show that the cost for the retrofit and the consumed nitrogen are low compared with the savings and gain in production time.

## **Acknowledgments**

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