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APPENDICES

Appendix A

In the TIG-snow process, liquid CO_2 (1) is expanded into gas and solid state and is transported through an inner flexible or rigid high-pressure snow nozzle. The snow nozzle is contained in an outer flexible or rigid tube, which houses a stream of filtered, heated, and ionized inert gas (TIG). The two elements are combined using a converging or diverging TIG nozzle assembly, which accelerates the snow to supersonic velocity in accordance with the Bernoulli principle.

Thermally ionized gases include clean-dry-air, nitrogen, or CO_2, These gases are used as a heated propellant. The kinetic energy contained in the supersonic velocity of the gas is transferred to the snow particles when the snow and TIG nozzles are coupled at the tip of the applicator. The nozzle assembly controls both spray pattern and impact velocity (a process called thrust vectoring). Both the cleaning power and snow usage are adjustable, which makes the technology adaptable for many different cleaning applications.

Environmental, Health, and Safety Considerations

When evaluating CO_2 snow cleaning technology, several process and environmental control factors must be considered. At a minimum, the cleaning process should be performed in a clean environment, preferably HEPA-filtered with adequate airflow to ensure that extracted contaminants do not redeposit onto cleaned surfaces.

Process control elements critical to the successful application of CO_2 snow cleaning include temperature control, ionization control, and CO_2 supply quality.
As with conventional precision spray cleaning processes, CO_2 snow cleaning requires a chemically pure and particle-free CO_2 supply to avoid deposition of background contaminants.

TIG-snow cleaning processes employ low-cost, nontoxic, recyclable, and readily available CO_2. Commercially available CO_2 is a recycled and abundant by-product obtained from a variety of natural and industrial sources. As such, it is not regulated by environmental agencies. Carbon dioxide is considered noncarcinogenic, but it is a simple asphyxiate, with an OSHA time-weighted average exposure limit of 5000 ppm and short-term exposure limit of 30,000 ppm.

There are no known harmful effects of repeated inhalation of low concentrations of CO_2. Carbon dioxide is shipped and stored with a DOT classification as a nonflammable liquid. The TIG-snow process is noncorrosive, nonflammable, and does not produce waste by-products that are typical of conventional cleaning, alternatives.

The User's Point of View

Several customers who own and use TIG-snow cleaning systems were asked to share their insight and perspective regarding CO_2 snow cleaning. Interview topics generally related to the application and use of the technology in their production operations and touched on such factors as product type, cleaning requirements, past cleaning methods, and results of the process change.

Replacing Solvents, Improving Quality

CP Clare Corporation manufactures and supplies delicate electronic switches and relays for the communication, security, automotive, and medical industries.
"We require the surface of our components to be free of particles, trace residues. And oxides prior to high-vacuum sputtering," stated Mike Keys, senior manufacturing engineer. "In the past, we used conventional CFCs and needed to eliminate them due to environmental regulations. For the most part, the old system worked well; however, occasional y the solvent became contaminated an created problems."

CP Clare was using a drum of solvent per week at a cost of $1500 and an equal cost to dispose of the spent cleaning agent. In addition to that, the company incurred an expense in maintaining a special environment for the cleaning system. "We found that the ultrasonic solvent process had difficulty breaking the bond of the particle from the substrate," remarked Keys. "However, the TIG-snow process, being velocity-based, proved to do a much better and more consistent job for us.

"Another problem that was cured was the issue of re-deposition of contamination due to drag out from one tank to the next. In general, we chose CO_2 snow cleaning because of its momentum transfer capability. It also saves us time, money, and is more consistent than our old process. We even noticed that our product's electrical characteristics improved with TIG-snow cleaning, and carbon dioxide is flat out cheap compared to chemical processes.

"Another benefit is that we do not require any special emissions control area as we did with the solvent process," Keys continued. "So we clean and go straight into our vacuum system. In my opinion, the system is simple to operate. We worked with the process parameters in the beginning until we were satisfied, and now its as easy as pushing a button, walking away from the process, and coming back when it's finished. Our TIG-snow cleaning process is twice as fast as the old Freon process, with less operator interface and maintenance."

Keys went on to state that the TIG-snow system is also extremely flexible. By adjusting flow rates, the company has been able to minimize consumables. Because CP Clare devices are prone to electrostatic discharge (ESD), the built-it ionization process that is part of the TIG-snow cleaning system was a valuable feature for their particular application.

Breaking the Bonds of Magnetic Particles

"At Litton, one product we produce is the accelerometer assembly for inertial navigation and guidance systems in missiles and aircraft," said Bob Bauman, manufacturing/process engineer for Litton Guidance and Controls.

"Within the accelerometer there is a strong magnet that attracts metallic particle, and there are small gaps between moving parts within the instrument. This particulate contamination is devastating to the performance of the instrument an, was the largest cause of accelerometer failures during testing. We can tolerate nonparticulate contamination on the magnet prior to, or after, assembly."

According to Bauman, the company had previously used chemical sprayers to trial to remove the particulates. While the sprayers worked well on residue-type contamination and loose
foreign material, they were relatively ineffective in removing particulates held by the magnetic field.

"We resorted to hand cleaning particles out manually using sticky picks, which was time consuming and inconsistent," Bauman stated. "During our evaluation c new options, we came across the TIG-snow process, and it is the best particulate removal method we have found."

With the TIG-snow system, Litton Guidance and Controls consumes approximately 50 pounds of CO_2 every 10 to 14 days, depending on production. The management team has found the new system to be cost effective as well as user friendly. Regarding cycle time, a sub-assembly (containing three magnets, other components, nooks, and crannies) can now be cleaned in less than one minute compared with the 10 to 15 minutes it once took by hand.

"We had not been able to achieve the same result with other cleaning methods, especially cleaning the magnetically held particles. We had established that particulate contamination was the primary cause of the failures and are convince the Yield improvement is significant," concluded Bauman.

A Leg-up in the Hard Disk Drive Industry

Marek Dragon, contamination control engineer for Xolox Corporation, also had good things to say about TIG-snow cleaning technology.

“We provide crash stop and actuator assemblies to the hard disk drive industry," explained

Dragon. "Because our components go into hard disk drives, they must be very clean. We have different requirements for different parts. For example, a significant portion of our parts is allowed to have 250,000- to 0.5-micron particles [or smaller].
However. Our requirements for other parts, such as our magnetic parts, are more stringent. Our requirement for allowable magnetic particles is basically zero. "

According to Dragon, the company routinely subjects parts to particle-counting tests to confirm cleanliness. Parts are also subject to a nonvolatile residue test (NVR). Two to three micro- grams of NVR per square centimeter is the upper limit.

"In the past, we attempted to use compressed ionized air to remove particles," Dragon stated. "We found the ionized air process to be effective at removing the larger particles, but ineffective at removing the smaller particles (Figure 6). It was totally ineffective at removing the magnetically charged particles. A few years ago we found the TIG-snow process to be very effective at removing all particles, including magnetically charged submicron particles (Figures 7 & 8, below).

According to Dragon, the new process is meeting company requirements at approximately 3 to 5 seconds per piece. The system has also proven itself easily adaptable to the automated processes within the operation and is used for many different applications.

"The CO_2 used in the system is a recycled by-product, so for us there really are no environmental concerns associated with the process," remarked Dragon. He added, however, "since CO_2 has the ability to deplete oxygen, you do need to consider the area of use."

Xolox put a TIG-snow system into their operation and currently use it approximately 4 to 24 hours per day, depending on production. "When properly applied with the appropriate fixturing, we could reduce our scrap rate by 90 percent," claimed Dragon. "That translates into a good yield improvement.

Stubborn Carbon Soil Removal

Seagate Technology cleans laser-welding fixtures for disk drive suspensions. The fixtures collect carbon soils in their guide holes, which accurately navigate the laser. Prior to using the TIG-snow process, cleaning was accomplished by swabbing each hole with IPA and/or
acetone.

Said Seagate Laser Welding Engineer David Buedorf, "Since the implementation of the system, we have achieved an estimated 2-3 percent yield improvement.

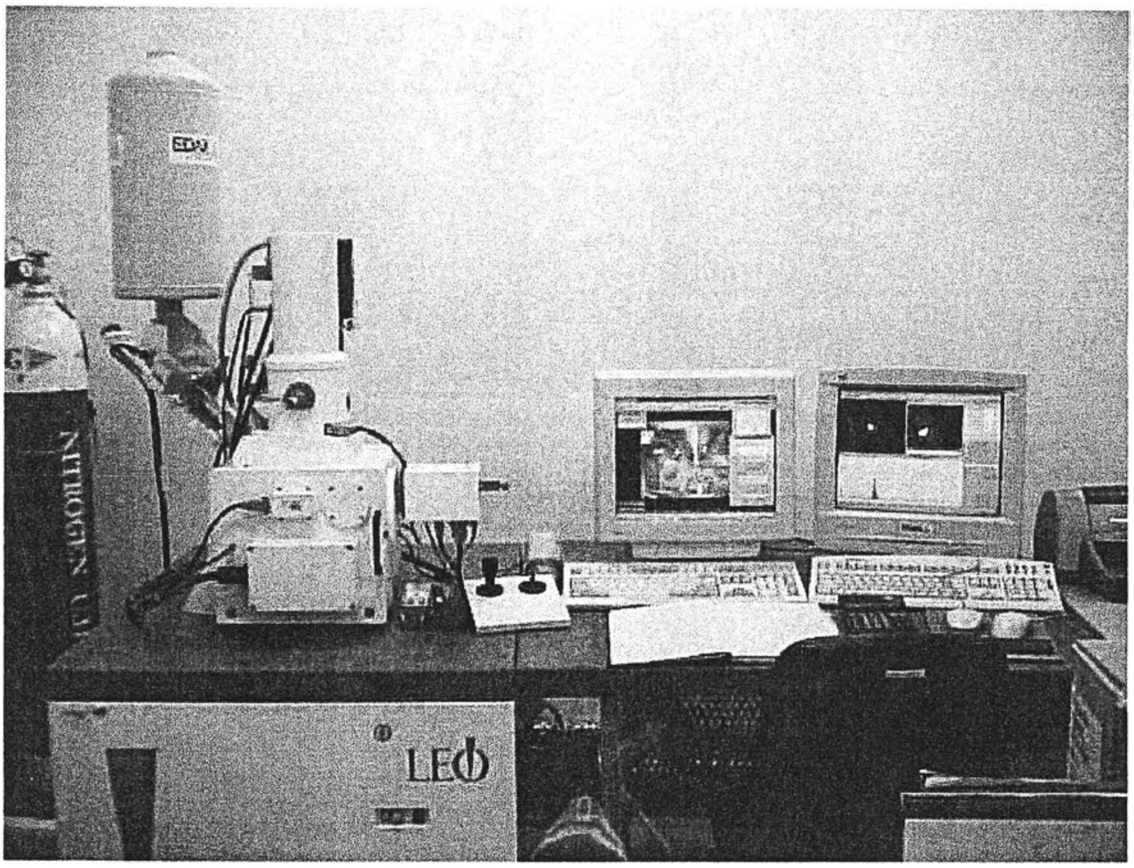
Cleaning time has been reduced to one-fifth of the original time needed, and the improved fixture cleaning results in longer production runs between cleanings."

A Snow for All Seasons...

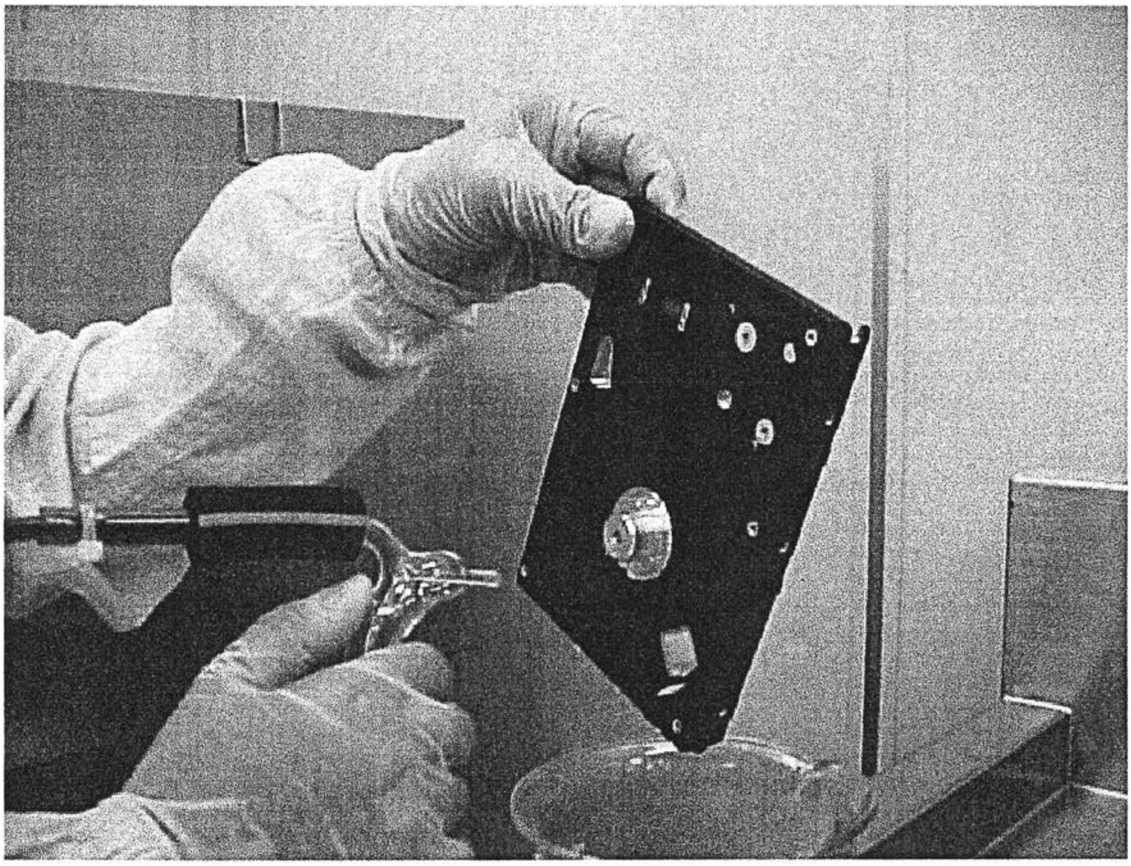
Many manufacturing companies have implemented CO_2 snow cleaning technology within their production operations, attracted by its unique features and benefits. These companies produce a variety of commercial products for the automotive, aircraft, aerospace, computer hard disk drive, medical, semiconductor, laser, and display system markets. In applications where both precise cleanliness and production objectives must be achieved, the technology has proven to be mechanically reliable, consistently effective, easy to use, and economical.

Cleaning with CO_2 snow also provides significant environmental benefits over other more conventional alternatives. These include the elimination of issues stemming from environmental permits due to hazardous air and water waste, bat degradation and maintenance, and worker safety.

Appendix B

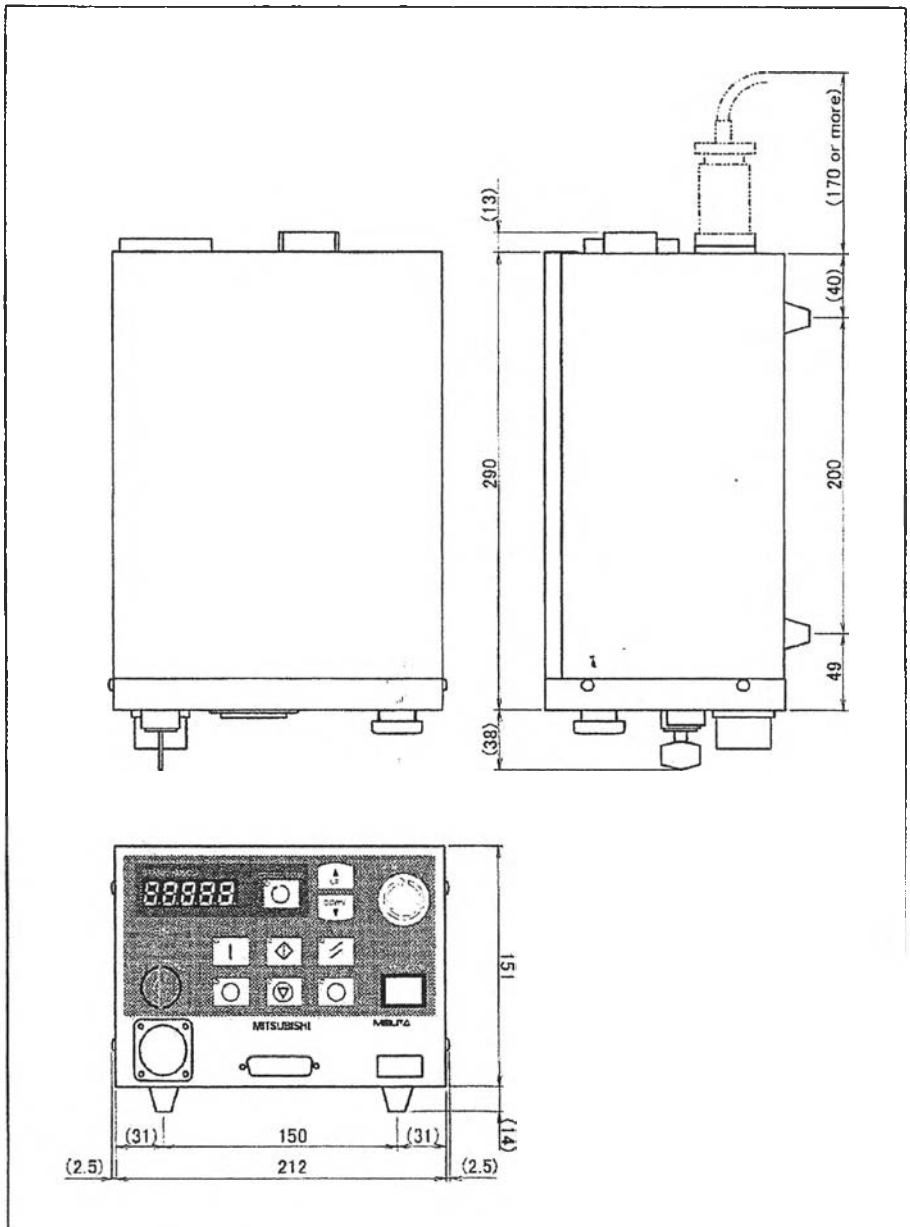


Scanning Electron Microscope

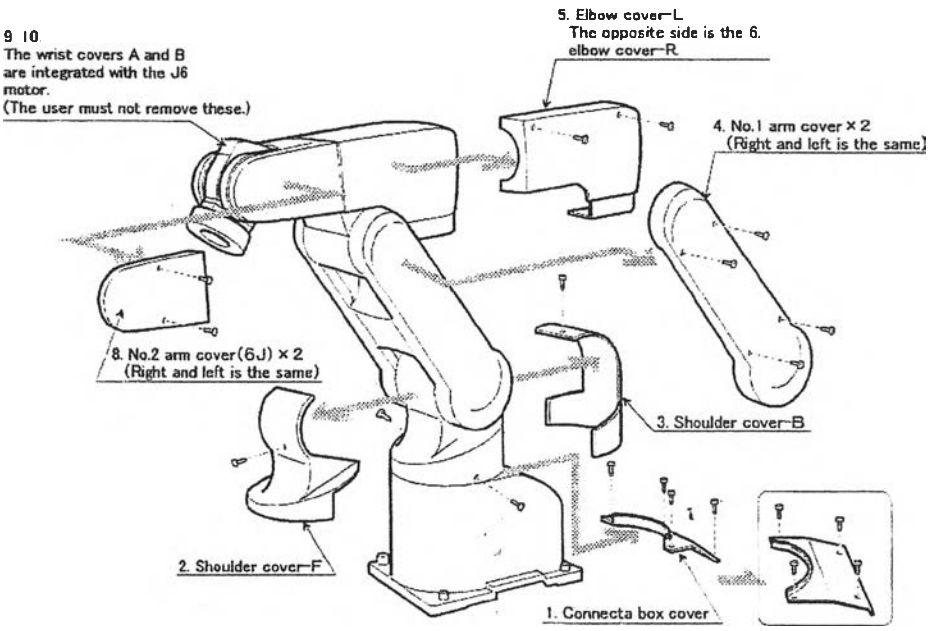


Spray Method for Liquid Particle Count Proceeding

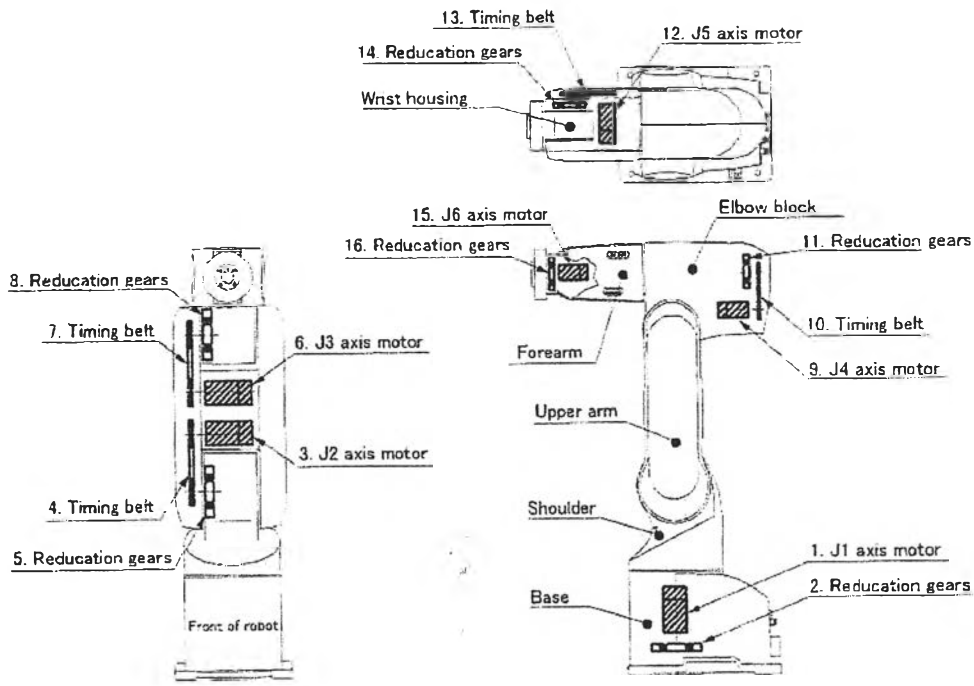
Appendix C



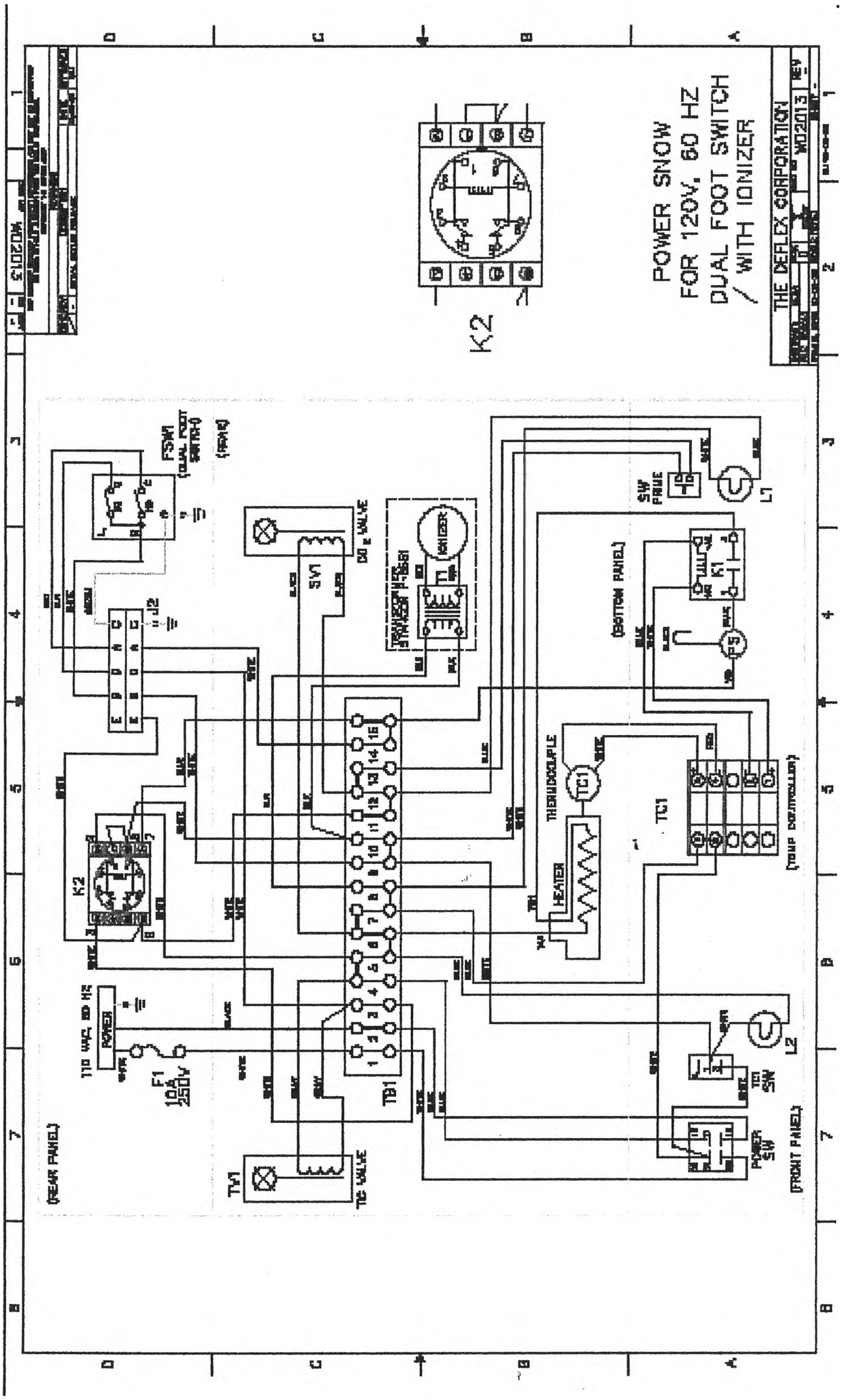
Outside dimensions of controller



Installing/removing the cover (6-axis type)



Outline structure drawing of robot arm (6-axis type)



Snow Power Control Box diagram

BIOGRAPHY

Bundhit Markthongdee was born on September 9, 1965 in Bangkok, Thailand. He obtained his Bachelor's degree in Industrial Engineering from Kasem Bundit University in 1992. He had started working at Seagate Technology during the period from 1986-1992, then worked at Semiconductor Venture International Co. LTD from 1992 to 1993 and worked at Fujitsu Thailand Company during the period from 1993-1997. Presently, he has worked at IBM Storage Products Thailand Limited since 1997- up to present time. In the past seventeen years experience in Hard Disk Drive manufacturing, his responsible job is related to quality assurance and process engineering. His current position now is Process Engineering Manager and responsible for cleaning, contamination control and Micro Drive manufacturing engineering. In 2000; He continues to study post-graduate for master degree of Engineering Management at The regional Centre for manufacturing Systems Engineering, Chulalongkorn University and University of Warwick (UK).