

Machine Shop Safety

A Look at the Woods Hole Oceanographic Institution Program

By Ronald H. Reif, Daniel S. Lopes and Sean M. Medeiros

The machine shops at Woods Hole Oceanographic Institution (WHOI) play a critical role in enabling its mission of world-class ocean science through the design, fabrication and maintenance of ships, vehicles and facilities that are used to work anywhere in the world's oceans. WHOI has approximately 25 machine shops in all major laboratory buildings on two campuses located in Woods Hole, MA.

The machine shops range in size and type, from a larger than 900 m² facility operated by professional machinists to one smaller than 20 m² operated by research personnel. These machine shops use various large floor-type and small tabletop machinery, including water jet cutters, press brakes, lathes, milling machines, table saws, band saws, drill presses, laser cutters and grinders. The machine shops perform maintenance, repair, fabrication and installation work on scientific instruments, shipboard equipment, hoisting equipment, physical plant and other mechanical systems.

WHOI has experienced serious injuries in its machine shops, including a 2015 in-

cident involving a waterjet machine that cuts thick metal parts. The incident led to enforcement action from OSHA, which served as a wake-up call for WHOI to comprehensively review and enhance the safety of its machine shops. This article describes WHOI's machine shops and their purpose, hazards, controls, key elements of a comprehensive safety program, fire prevention and waste management.

Machine Shops & Applications

The WHOI mechanical shop staffed by professional machinists is comprised of three groups: instrument, mechanical and welding. The instrument group includes a fully equipped prototype machine shop with three-axis computer numerical control (CNC) milling capability and a CNC lathe. Its function is to design, construct, modify and repair precision components or assemblies of oceanographic instrumentation.

The staff consists of experimental machinists who are knowledgeable about the stresses induced by the oceanographic environment. Shipboard needs are also addressed when equipment repairs or installations are required on WHOI's fleet of coastal and ocean-class research vessels. This group can handle complex shaping and turning operations on ferrous and nonferrous materials.

IN BRIEF

- This article describes Woods Hole Oceanographic Institution's (WHOI) various machine shops, including shops with professional machinists and satellite machine shops used by research personnel.
- It discusses hazards in machine shops, including a serious injury at WHOI that resulted in an OSHA citation and penalty.
- Finally, it describes the development and implementation of a comprehensive machine shop safety program.

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In addition, complete capabilities including welding exist for fabrication of plastic components. Photo 1 shows a hydraulic press brake located in WHOI's largest machine shop that is equipped with a presence-sensing device and two-hand actuators on the operator's control bar.

The mechanical group has skilled mechanics who accomplish heavy repairs and installation of shipboard equipment including engines, generators and winches. They perform shoreside repair of the institution's physical plant and assist the scientific staff with heavy construction of scientific equipment such as mooring structures, dredges and core samplers. Photo 2 shows a CNC milling machine with sliding access doors that are interlocked to the machine's power supply.

Approximately 23 satellite machine shops are operated by research personnel. These shops are located within laboratory buildings and include smaller machinery such as mills, lathes, drill presses, band saws and grinders. The satellite machine shops allow the research personnel to perform machining work on smaller parts. Machining work on larger parts is performed by the WHOI mechanical shop's professional machinists. Photo 3 shows a satellite machine shop that includes a tabletop mill-lathe combination machine, with chuck guards that are interlocked to the machine's power supply.

Machine Shop Hazards

Serious injuries and fatalities have occurred in machine shops throughout the U.S. (OSHA, 2007). Because WHOI's 23 satellite machine shops are located in all major laboratory buildings on two campuses, a critical need exists to prevent access to potentially hazardous machinery by unauthorized persons. On April 12, 2011, Michelle Dufault, a Yale University undergraduate student, was killed when her hair was caught in a lathe (Foderaro, 2011). Dufault worked on underwater robotic vehicles the previous summer as a student fellow at WHOI.

In 2016, WHOI received an OSHA citation and notification of penalty. This enforcement action was the result of an incident involving a waterjet machine that cuts thick metal parts. A machinist suffered serious hand lacerations that resulted in emergency surgery and an overnight hospitalization. Had the machinist's hand been at a slightly different angle, it would have been amputated. OSHA cited WHOI with a serious violation under 29 CFR 1910.212(s)(1) (OSHA, 1973), stating, "OMAX Water Jet Machine was not adequately guarded to prevent workers from being injured by the water jet emanating from the nozzle." The injured machinist violated the operating procedure that prohibits more than one operator from using the water jet machine. At the time of the injury two operators were using the water jet machine, with one of the operators positioning the metal piece for cutting. The abatement of violation included installing a pressure-sensing mat in front of the water jet and training all machinists on the operating procedure.

As a result of the 2016 enforcement action, WHOI hired a senior consultant to inspect all of



Photo 1: Hydraulic press brake equipped with presence-sensing device and two-hand actuators on the operator's control bar.



Photo 2: CNC milling machine with sliding access doors that are interlocked to the machine's power supply.



Photo 3: Satellite machine shop that includes a tabletop mill-lathe combination machine with chuck guards that are interlocked to the power supply.



Photo 4: An older horizontal band saw that did not meet WHOI's requirement that safeguarding have an opening no larger than 6 mm (0.25 in.).

TABLE 1

Summary of Machine Shop Hazard Classification

Criteria	Machinery class		
	Class 1	Class 2	Class 3
Power/type	Portable tools (corded, cordless)	Industrial tools/machines	Higher hazard industrial tools/machines
Examples	<ul style="list-style-type: none"> •circular saw •belt sander •reciprocating saw •miter saw •router •angle grinders •small (mini) benchtop drill press •small (mini) benchtop band saw 	<ul style="list-style-type: none"> •full-size drill press •full-size band saw •small benchtop milling machine •small benchtop metal lathe •small benchtop woodturning lathe •bench grinder, surface grinder •planer, jointer •horizontal saw, radial arm saw •power sheer, shaper/molder •water jet •laser cutter/engraver (enclosed or eye-safe) •SawStop-equipped table saw 	<ul style="list-style-type: none"> •full-size milling machine •full-size metal lathe •table saws that are not SawStop-equipped
Shop access control	Standard door lock	Door lock approved by director of facilities	Door lock approved by director of facilities
Tool access control	Permission from space owner	Permission from shop supervisor	Permission from shop supervisor
User restrictions		Certified as authorized user by shop supervisor	<ul style="list-style-type: none"> •shop supervisor present •certified as authorized user •buddy system recommended
User training	<ul style="list-style-type: none"> •machine shop safety online training •follow manufacturer's instructions 	<ul style="list-style-type: none"> •machine shop safety online training •tool-specific training from shop supervisor 	<ul style="list-style-type: none"> •machine shop safety online training •tool-specific training from shop supervisor
Shop supervisor training		Approved by director of facilities	Approved by director of facilities

its machine shops. From this inspection, WHOI developed a corrective action tracking sheet to address the findings. Due to a significant number of older machines present on both campuses, inadequate machine guarding (i.e., safeguarding) was the most frequently identified opportunity for improvement.

Photo 4 (p. 31) shows machine guarding for a horizontal band saw that did not meet WHOI's requirement that machine safeguarding have an opening no larger than 6 mm (0.25 in.). All machines with inadequate guarding or other safety-related issues were locked out of service until repaired or replaced. If repair was not cost effective or feasible, then the machine was disposed of.

Safeguarding is used for preventing or controlling personnel from coming in contact with the moving parts of machinery or equipment that have the potential to cause physical harm. Mroszczyk (2012) describes various mechanical hazards, all of which could be present in WHOI's machine shops. Following are examples of these hazards.

- Catch points are created by stationary or moving objects with sharp corners or rough surfaces that could catch a person's clothing or skin.

- Falling materials are objects that are falling with sufficient force to hit and injure a person.

- Flying materials are objects in motion with sufficient force to hit and injure a person.

- In-running or nip points are created when two moving objects move progressively closer until they contact or come close together, and could pull a body part into the constricting space and crush it.

- Pinch points are created when two objects come within close proximity (e.g., 6 mm or 0.25 in.) such that human flesh could be pinched.

- Sharp points are edges or points that could cut or puncture a person's skin.

- Shear points are created from at least two objects with relatively sharp edges that come together such that a body part could be cut by the shearing action.

- Squeeze points are created by two objects, with at least one being in motion, that are moving toward each other. A hazard exists when the objects come close enough to squeeze a body part.

Comprehensive Safety Program

In response to the OSHA citation, WHOI developed a comprehensive machine shop safety program in 2016. Prior to 2016, WHOI's machine shop

safety program consisted of an online machine shop training module and a one-page shop safety rules document that was posted in all machine shops. The first step of the improvement process was to review all machine shops and compile an inventory of the machinery and personnel using it. From the inventory, WHOI developed a machine shop hazard classification system, which categorizes machinery into class 1, 2 or 3.

Class 3 machinery is considered to be the most hazardous and includes full-size milling machines and lathes, and table saws not equipped with the SawStop safety technology or equivalent (SawStop, 2018). An approved shop supervisor must be present during operation of class 3 machinery and users must be certified as authorized operators by the shop supervisor, which includes machine-specific training.

Class 2 machinery is considered medium hazard level. Examples of class 2 machinery are full-size drill press, full-size band saw, benchtop lathe, horizontal band saw, water jet, bench grinder and table saw equipped with SawStop technology or equivalent. Operators must be certified as authorized operators by the shop supervisor, which includes machine-specific training.

Class 1 machinery is considered low hazard level. Examples of class 1 machinery are circular saw, belt sander, reciprocating saw, miter saw, router and benchtop band saw. Users of class 1 machinery must have permission from the shop owner. All users of class 1, 2 and 3 machinery must complete WHOI's online machine shop safety training initially and every 2 years thereafter.

WHOI's machine shop safety program is documented in a guideline and training. This guideline is integrated into WHOI's overall safety management program and includes the following program elements:

- roles, responsibilities and authorization process;
- machinery maintenance and hazard controls;
- shop safety rules and PPE;
- fire prevention;
- shop inspections and reporting;
- waste management.

The safety inspections are intended to proactively identify and correct hazardous conditions, while the incident program is designed to identify the causes of incidents, share lessons learned and prevent recurrence. Table 1 provides an example summary of the machine shop hazard classification system included with WHOI's machine shop safety guideline to help shop supervisors and authorized operators implement the requirements. The safety management program, guidelines and training are available on WHOI's (2018) website.

Roles, Responsibilities & Authorization Process

Multiple groups were involved in the machine shop safety program implementation, including the facilities department, environment health and safety (EH&S) department, machine shop supervisors and authorized operators. The EH&S department oversees WHOI's machine shop

safety program, which includes the machine shop safety guideline and the online machine shop safety training. Annual safety inspections and incident investigations are conducted by the EH&S department.

The facilities department approves class 2 and 3 shop supervisors. In some cases, this may involve vetting of prospective machine shop supervisors by professional machinists within the facilities department. This vetting process involves having the prospective class 2 or 3 shop supervisors demonstrate the safe use of machinery that will be under their oversight and reviewing the oversight responsibilities for a class 2 or 3 machine shop. The facilities department assists with maintenance of the machine shops and machinery.

Shop supervisors play a critical role in overseeing the individual machine shops with class 2 and 3 machinery. Shop supervisors oversee all aspects of machine shops including equipment maintenance, machine-specific training, controlling access to hazardous machinery, implementing safety guidelines and approving authorized operators. Shop supervisors must be experienced and competent in the safe use of all tools and machinery in the machine shop, meet the definition of a competent person and be familiar with the safe operation of all shop machines, equipment and tools.

Shop supervisors approve of and maintain a list of authorized operators for each class 2 and 3 machine. The vetting process for authorized operators involves the prospective class 2 or 3 operators demonstrating the safe use of machinery that will be under their use and reviewing their understanding of the shop safety rules. Authorized operators may only use machinery that they have been certified to operate by the shop supervisor and are required to follow all shop safety requirements. Shop supervisors must be present during the operation of class 3 machinery. When the shop supervisor is not on site, authorized operators may use class 2 machinery provided that they take on the machine shop oversight responsibilities of the shop supervisors.

Machinery Maintenance & Hazard Controls

Shop supervisors and authorized operators are responsible for ensuring that machinery is properly maintained and in good working order. Machinery that is unsafe to operate must be immediately locked and tagged out of service. A machine with a missing or inadequate safeguard would be an unsafe condition that requires that the machine be locked and tagged out of service until proper repairs are made. Photo 4 (p. 31) shows an example of an unsafe machine needing corrective action.

Hazard controls such as machine safeguards must be adequate to safely control or eliminate the various hazards that may be present in a machine shop. At a minimum, WHOI's machine shop safety program is designed to comply with OSHA's machinery and machine guarding requirements (OSHA, 1973). NSC's *Accident Prevention Manual for Business and Industry* (Hagan, Montgomery &



Photo 5: Key-operated selector switch that controls electric power to class 3 machinery.

O'Reilly, 2009) states that it is common practice in the design of point-of-operation safeguards to consider any opening of 9 mm (0.375 in.) or less to be relatively safe but acknowledges that a smaller opening of 6 mm (0.25 in.) would better protect fingers from entering the danger zone. WHOI has adopted 6 mm as a design requirement for point-of-operation safeguards. Mroszczyk (2012) describes various machine hazards and controls. Some common hazard controls used in WHOI's machine shops include:

- lathe and milling machine chuck wrenches with springs that prevent the wrench from being left in the chuck;
- machine control bars with optical two-hand actuators, where concurrent depression of both buttons is necessary for machine operation;
- guarded foot switches to prevent inadvertent machine actuation and position operator away from danger zone;
- electrically interlocked physical guarding;
- electrically interlocked pressure-sensing mats;
- barricades and enclosures.

Multiple machine shops at WHOI include class 2 and 3 machinery that may be used by personnel from different departments. To prevent unauthorized operation of class 3 machinery by unauthorized personnel, the power supplies to class 3 machinery are equipped with key-operated selector switches (Photo 5). These restricted keys are only issued to class 3 shop supervisors and authorized operators. It is the shop supervisor's responsibility to control access to the restricted keys for that machine shop.

Shop Safety Rules & PPE

Shop safety rules with the hours of operation are posted at WHOI's machine shops. These rules are reviewed and signed by all authorized operators of class 2 and 3 machinery. A shop notice with the shop supervisor's name and contact numbers is posted at the entrance to each machine shop. The shop notice states that only trained and authorized personnel may operate machinery.

At a minimum, safety glasses and closed-toe shoes must be worn by all personnel working in machine shops. Shop supervisors are required to conduct a hazard analysis of the operations occurring within their machine shops to identify the need for additional PPE. Following are examples of PPE that may be required depending on the results of the hazard analysis:

- Eye and face protection is required when there is a potential for flying materials.
- Head protection (hard hats) is required when working with an overhead crane or if there is the potential for head injury from falling objects.
- Hearing protection is required during certain cutting, grinding and other noisy operations, or if personnel are working in designated hearing conservation areas.
- Protective footwear is required when potential exists for foot injury from rolling or dropped objects.
- Protective gloves are required if hands can be cut or injured from hazardous materials contacting the skin.

Fire Prevention

All machine shops must be in compliance with WHOI's combustible dust safety procedure. This procedure defines combustible dust as any finely divided solid material that presents a fire or ex-

FIGURE 1
Safety Inspection Form

Woods Hole Oceanographic Institution
Environmental, Health & Safety Office

SPACE OWNER: _____
DEPT: _____
LOCATION: _____
DATE: _____
PARTICIPANTS: _____

Inspection results represent a sample of environmental, health and safety issues that may exist in the referenced work area(s). The inspection is not comprehensive, not all areas or activities are reviewed. Supervisors or designees should use the results as a guide to identify and correct similar and/or other environmental, health and safety issues in their area(s)

Priorities: 1 - Immediate Hazard 2 - Safety Requirement 3 - Best Management Practice

Item	Location	Description	Corrective Action	Assignment	Priority	Status

plosion hazard when dispersed and ignited in air. Proper housekeeping and maintenance is a key part of preventing a combustible dust fire and explosion. Machine shops are required to remove combustible dust residue from shop surfaces, including duct work, such that no more than 3 mm (0.125 in.) of dust is allowed to accumulate.

Hot work such as welding and grinding occurs in several of the institution's larger machine shops. Hot work must be conducted in authorized, controlled areas or under a hot-work permit. Flammable and combustible materials within a 35-ft radius of the hot work are required to be removed or adequately protected from heat, sparks and hot slag. Oily rags have been reported to start fires by spontaneous combustion (Evarts, 2011). Within each machine shop, oily rags are collected in listed and approved steel waste cans with self-closing lids and collected by our hazardous waste contractor on a weekly basis.

All machine shops are protected with sprinkler systems and are equipped with Class ABC portable fire extinguishers. The larger machine shops that generate significant quantities of metal shavings and turnings are equipped with Class D portable fire extinguishers. The EH&S department provides live-fire training with portable fire extinguishers.

Shop Inspections & Reporting

Safety inspections are a proactive method for identifying and correcting an unsafe condition. The EH&S department conducts annual safety inspections of all machine shops. On the inspection report form (Figure 1), immediate hazards must be corrected right away, safety requirements must be corrected within 30 days and best management practices are optional. Corrective actions are assigned to individuals on the inspection report form and tracked to closure by the EH&S department. The EH&S department uses a corrective action tracking system to track and document closure of corrective actions. Daily or before using machinery, shop supervisors conduct self-inspections of their machine shops to ensure compliance with the shop safety requirements.

Incidents and near-hits are reported with an online form by those involved in the incident or their supervisor. In addition to describing the incident, contributing causes and methods for preventing recurrence are documented on the online reporting form. The EH&S department investigates all incidents and near-hits that are reported to verify what happened, identify the cause and identify corrective actions that will prevent recurrence.

Waste Management

Waste management within WHOI's machine shops starts with waste minimization and recycling. Waste metal in the form of shavings, turnings and unusable pieces are recycled. At the end of each shift, waste metals are segregated by type (e.g., stainless steel, carbon steel, aluminum and titanium) and collected for recycling. WHOI maximizes the use of chemical products (e.g., cutting

fluids) that result in nonregulated waste streams (i.e., not defined as a hazardous waste by Massachusetts Department of Environmental Protection). Regulated waste streams that are considered hazardous waste by Massachusetts Department of Environmental Protection are segregated and collected in satellite accumulation areas. The EH&S department conducts comprehensive waste management training for all waste generators that covers waste minimization, recycling and hazardous waste management.

Conclusion

With 25 machine shops located in all major laboratory buildings on both campuses, WHOI is dependent on the critical role that these machine shops play in enabling its mission of world-class ocean science. Serious injuries and fatalities have occurred in machine shops throughout the country. WHOI has experienced serious injuries in its machine shops, including an incident involving a waterjet machine in which a machinist suffered serious hand lacerations. The incident led to an OSHA enforcement action in 2016.

That action prompted WHOI to develop a comprehensive machine shop safety program. Since doing so, shop supervisors have been designated for all machine shops, authorized operators have been trained and are implementing applicable elements of the program and all machines are in compliance with WHOI's safeguarding criteria. Since implementing a comprehensive machine shop safety program, no OSHA-recordable injuries or illnesses have occurred as a result of working with machinery in WHOI's machine shops. **PS**

References

- Evarts, B. (2011). Fires caused by spontaneous combustion or chemical reaction (Report). Quincy, MA: NFPA. Retrieved from www.nfpa.org/news-and-research/fire-statistics-and-reports/fire-statistics/fire-causes/chemical-and-gases/spontaneous-combustion-or-chemical-reaction
- Foderaro, L.W. (2011, Apr. 13). Yale student killed as hair gets caught in lathe. *New York Times*. Retrieved from www.nytimes.com/2011/04/14/nyregion/yale-student-dies-in-machine-shop-accident.html
- Hagan, P.E., Montgomery, J.F. & O'Reilly, J.T. (Eds.). (2009). *Accident prevention manual for business and industry: Engineering and technology* (13th ed.). Itasca, IL: NSC.
- Mroszczyk, J.W. (Ed.). (2012). *Safety engineering* (4th ed.). Des Plaines, IL: ASSE.
- OSHA. (1973). Machinery and machine guarding (29 CFR 1910.212). Washington, DC: U.S. Department of Labor, Author. Retrieved from www.osha.gov/pls/oshaweb/owadis.show_document?p_table=standards&p_id=9836
- OSHA. (2007). *Safeguarding equipment and protecting employees from amputations* (Publication No. 3170-02R). Retrieved from www.osha.gov/Publications/OSHA3170.pdf
- SawStop. (2018). How it works. Retrieved from www.sawstop.com/why-sawstop/the-technology
- Woods Hole Oceanographic Institution (WHOI). (2018). Environmental health and safety introduction. Retrieved from <http://ehs.whoi.edu>