

Titolo

Specifica tecnica di fornitura e set-documentale relativo all'approvvigionamento di una macchina di Detonation Spray per la realizzazione di coating su materiali strutturali.

Descrittori

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Sommario




I processi di deposizione basati sul metodo Detonation Spray sono di grande interesse per la comunità scientifica LFR, in quanto consentono la deposizione di strati sottili, fino a 20µm su substrati austenici e ferritici.


Il presente documento sintetizza le attività in corso sul DS presso ENEA Brasimone.

Note

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0	EMISSIONE	25/09/2012	NOME	Alessandro Gessi	M. Tarantino	M. Tarantino
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1. INTRODUCTION

Thermal spraying is an effective and low cost method to apply thick coatings to change surface properties of the component. Coatings are used in a wide range of applications including automotive systems, boiler components, and power generation equipment, chemical process equipment, aircraft engines, pulp and paper processing equipment, bridges, rollers and concrete reinforcements, orthopedics and dental, land-based and marine turbines, ships [1]. Among the commercially available thermal spray coating techniques, Detonation Spray (DS) and High Velocity Oxy Fuel (HVOF) spray are the best choices to get hard, dense and wear resistant coatings as desired. The objective of the work is to analyze the role of detonation gun spray coating to enhance the properties of surface of substrate to counter the problems like erosion, residual stress, fretting fatigue, thermal behavior and corrosion etc.

2. THERMAL SPRAYING

Thermal spraying has emerged as an important tool of increasingly sophisticated surface engineering technology. The different functions of the coating, such as wear and corrosion resistance, thermal or electrical insulation can be achieved using different coating techniques and coating materials. Thermal spraying is the application of a material (the consumable) to a substrate by melting the material into droplets and impinging the softened or molten droplets on a substrate to form a continuous coating. There are many thermal spray coating deposition techniques available, and choosing the best process depends on the functional requirements, adaptability of the coating material to the technique intended, level of adhesion required, (size, shape, and metallurgy of the substrate), and availability and cost of the equipment. Thermal spray processes that have been considered to deposit the coatings are enlisted below:

- (1) Flame spraying with a powder or wire
- (2) Electric arc wire spraying
- (3) Plasma spraying
- (4) Spray and fuse
- (5) High Velocity Oxy-fuel (HVOF) spraying
- (6) Detonation Gun.

3. DETONATION GUN SPRAYING

D-gun spray process is a thermal spray coating process, which gives an extremely good adhesive strength, low porosity and coating surface with compressive residual stresses. A precisely measured quantity of the combustion mixture consisting of oxygen and acetylene is fed through a tubular barrel closed at one end. In order to prevent the possible back firing a blanket of nitrogen gas is allowed to cover the gas inlets. Simultaneously, a predetermined quantity of the coating powder is fed into the combustion chamber. The gas mixture inside the chamber is ignited by a simple spark plug. The combustion of the gas mixture generates high pressure shock waves (detonation wave), which then propagate through the gas stream. Depending upon the ratio of the combustion gases, the temperature of the hot gas stream can go up to 4000 deg C and the velocity of the shock wave can reach 3500m/sec. The hot gases generated in the detonation chamber travel down the barrel at a high velocity and in the process heat the particles to a plasticizing stage (only skin melting of particle) and also accelerate the particles to a velocity of 1200m/sec. These particles then come out of the barrel and impact the component held by the manipulator to form a coating. The high kinetic energy of the hot powder particles on impact with the substrate result in a build up of a very dense and strong coating. The coating thickness developed on the work piece per shot depends on the ratio of combustion gases, powder particle size, carrier gas flow rate, frequency and distance between the barrel end and the substrate. Depending on the required coating thickness and the type of coating material the detonation spraying cycle can be repeated at the rate of 1-10 shots per second. The chamber is finally flushed with nitrogen again to remove all the remaining “hot” powder particles from the chamber as these can otherwise detonate the explosive mixture in an irregular fashion and render the whole process uncontrollable. With this, one detonation cycle is completed above procedure is repeated at a particular frequency until the required thickness of coating is deposited. The chamber is finally flushed with nitrogen again to remove all the remaining “hot” powder particles from the chamber as these can otherwise detonate the explosive mixture in an irregular fashion and render the whole process uncontrollable. With this, one detonation cycle is completed above procedure is repeated at a particular frequency until the required thickness of coating is deposited.

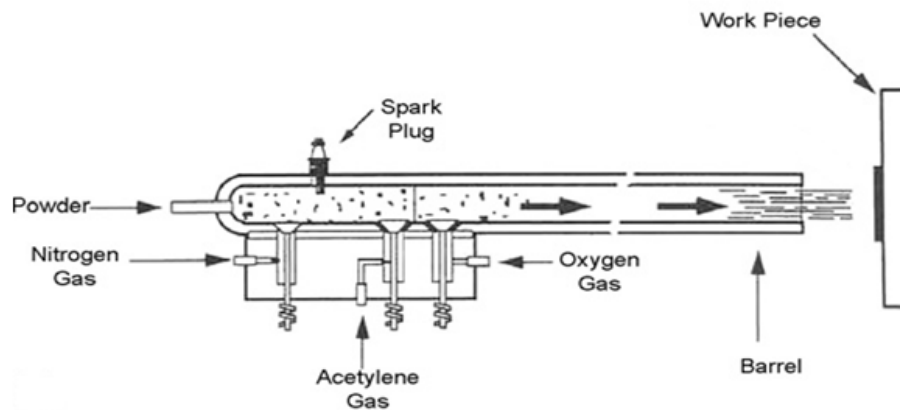


Fig.1. Detonation Gun process

4. THE ENEA DETONATION SPRAY EQUIPMENT

As a first step at ENEA Brasimone for coating manufacturing, CCDS200 DS coating machine from STPC company, Novosibirsk, Russia, has been purchased and installed. It has to be underlined that STPC is the only vendor worldwide of this machine, originally trademark of Praxair ® USA. Together with an installation at Grenoble University, it will be the only european facility DS based.

5. ANNEX

1. Detonation spraying technology Description
2. Thermal Spray Booth Design Guidelines

Detonation spraying technology Description

The detonation spraying complex «CCDS-2000» is designed to produce powder coating by spraying various powder materials on the surface of objects accessible for the direct high-speed spray flow. The complex consists of the detonation *gun (gun with manipulation system)*, the *control unit* and the *chiller*.

The working principle of the CCDS2000 gun is based on the following basic procedures:

- the barrel, open at one end, is filled with an explosive gas mixture;
- the portion powder is injected in the barrel;
- detonation is initiated at the closed end of the barrel; burning explosion products accelerate the powder, heating it up to the melting temperature and deposit it onto the object's surface;
- after each shot the barrel is purged by nitrogen;
- once the heated powder particles hit the working surface of the object they firmly attach to the surface forming a coating up to 10 microns thick;
- the desired thickness of coating is achieved by a sequence of shots, during which the object can be moved using the manipulator.

CCDS2000 D.Gun is controlled by the industrial computer unit, which is used to program the spraying procedure and to coordinate the movement of work piece; during the spraying process the computer unit controls the program's progress. The technology of spraying can be easily modified, and the programs can be stored on external media carriers (flash disks).

1. Facility Requirements

1.1 Ventilation and spray booth

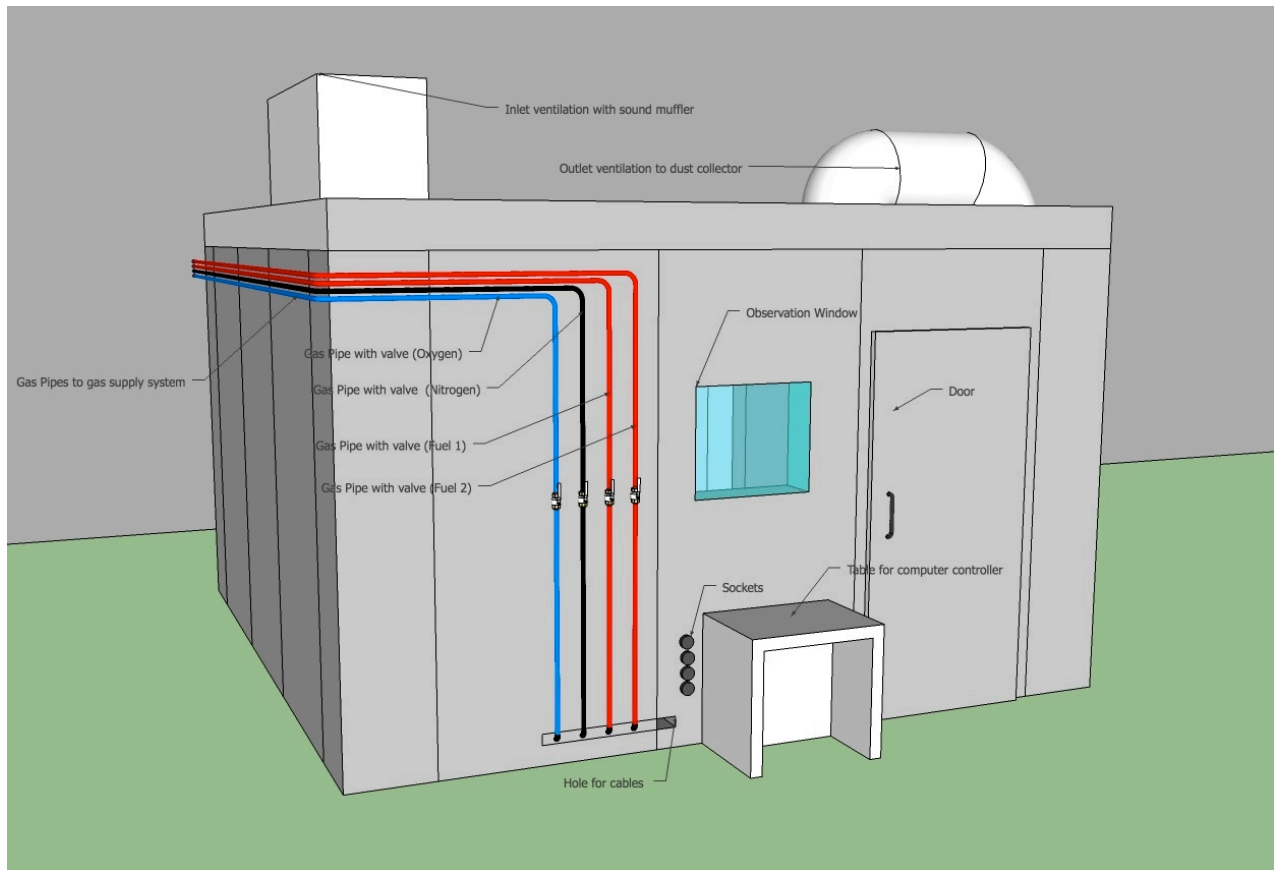
The CCDS2000 systems require a thermal spray booth with sufficient room (W/L 3.5m/3.5m or more), air ventilation and sound insulation. The spray booth should have forced ventilation that replaces the whole (95%) air volume every 1-2 minutes. The exhaust ventilation should have a dust collector. Noise mufflers should be installed in the inlet and outlet ventilation.

The lighting in the spray booth should be explosion-proof. The spray booth should have an easily breakable window at least 1 m² in area. In a wall of the spray booth should be a hermetic observation window of ~ 0.4 m² in area, made of double glass panes 20 mm thick, and a soundproof channel for cabling (~ 100 × 100 mm).

The compressed air source (8bar) should be in the spray booth (for target part cooling).

Door of spray booth should be equipped with switch, to be connected to computer controller, to control it.

Ventilation system should be equipped with switch, to be connected to computer controller, to control it.



Recommended spray booth design.

1.2 Sound Attenuation

Reduce the noise level from 140 dBA to the required safe 8-hour exposure limit. (In Russia, this is 85 dBA.) This can be done by enclosing the spray system in a properly designed booth that will absorb the sound. Due to specific nature of the detonation spraying process, spray booth should be able to absorb low frequency impulse noise. We recommend double wall design. Standard thermal spray booth (which is used for other thermal spray equipment) can't provide necessary sound isolation. Call your spray booth supplier for more information.

1.3 Safety Equipment

Your safety equipment should include appropriate ear protection for 135 dBA, safety goggles for eye protection, and clothing protection such as flame resistant laboratory coats. Respirators for breathing protection should also be part of safe thermal spraying.

1.4 Water

20 liters of filtered and clean water required for the CCDS2000 chiller.

Gas Supply System.

Gas supply system should be designed and produced by customer side according listed parameters.



Gas and Fuel Purity Recommendations
 Gas purity levels are important to optimum Detonation Gun life and proper system operation. Gases of at least 99.995 percent purity are preferred for prolonging the life of Detonation Gun equipment.

Acetylene gas parameters

Volume fraction of acetylene, %, not less-----	99.5
Volume fraction of air and other badly soluble in water gases, %,no more -----	0.5
Volume fraction of Phosphine PH ₃ , % no more-----	0.005
Volume fraction of hydrogen sulphide H ₂ S, % no more-----	0.002
Mass concentration of water steams at temperature 200 C and pressure 101.3 kPa , g/m ³ not above-----	0.4

1.5 Oxygen

A maximum oxygen flow of 10 m³/h at 1.5-1.6 bar is needed for CCDS2000 gun. **Use only stainless steel supply piping.** Usually, a minimum 1/2 inch (12.7 mm) ID stainless steel line (cleaned for oxygen service) is required, depending on the number of elbows in the line. A bulk liquid oxygen system may require a low pressure, high flow regulator, depending on the length of piping from the supply to the Gun. When using low pressure liquid oxygen cylinders, consult your factory representative for more information. When using high pressure cylinders, you must use two stage pressure regulation system, first special oxygen regulator to reduce pressure to 10 bar, and second HIGH FLOW oxygen regulator to reduce pressure to 1.5 bar .



The oxygen lines must be specially cleaned for oxygen service. Oils or contaminants in the lines can cause fire or explosion or equipment damage.

1.6 Acetylene Fuel

A maximum acetylene flow of 5 m³/h at 1.35-1.45 bar is needed for CCDS2000 gun. **Use only stainless steel supply piping.** Usually, a minimum 1/2 inch (12.7 mm) ID stainless steel line (cleaned for oxygen service) is required, depending on the number of elbows in the line. When using low pressure acetylene cylinders, use only HIGH FLOW acetylene regulator to reduce pressure to 1.5 bar.

Due to high level of consumption of the acetylene fuel we strictly recommend to use manifolded cylinders. At least four cylinders linked together.



Manifolding cylinders

1.7 Propylene/Propane Fuel

A maximum propylene/propane flow of 5 m³/h at 1.8 bar is needed for CCDS2000 gun. **Use only stainless steel supply piping.** Usually, a minimum 1/2 inch (12.7 mm) ID stainless steel line (cleaned for oxygen service) is required, depending on the number of elbows in the line. When using low pressure cylinders, use only HIGH FLOW propylene regulator to reduce pressure to 1.8 bar.

2.3.8 Inert Gas (Nitrogen)

A maximum nitrogen flow of 20 m³/h at 1.8-2.0 bar is needed for CCDS2000 gun. **Use only stainless steel supply piping.** Usually, a minimum 1/2 inch (12.7 mm) ID stainless steel line (cleaned for oxygen service) is required, depending on the number of elbows in the line. When using high pressure cylinders, you must use two stage pressure regulation system, first special nitrogen regulator to reduce pressure to 10 bar, and second HIGH FLOW nitrogen regulator to reduce pressure to 2 bar .

For any questions, contact STPC Ltd. stzp.company@gmail.com



Thermal Spray Booth Design Guidelines

Prepared by the ASM-TSS Safety Committee

Key Document Authors:

Douglas J. Gifford, Praxair Surface Technologies, Inc.

Larry Pollard, Progressive Technologies, Inc.

Gregory Wuest, Sulzer Metco (US), Inc.

Randy C. Fletcher, Praxair Surface Technologies, Inc.

TSS Safety Committee Members:

Gregory Wuest Chairman

Richard Neiser

Lysa Russo

Daryl Crawmer

Klaus Dobler

Douglas J. Gifford

Donna Guillen

Larry Pollard

Sulzer Metco (US), Inc.

Sandia National Laboratories

SUNY at Stony Brook

Thermal Spray Technologies, Inc.

St. Louis Metallizing Company

Praxair Surface Technologies, Inc.

Idaho National Engineering and
Environmental Laboratories

Progressive Technologies, Inc.



Thermal Spray Booth Design Guidelines

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Comments, criticisms, and suggestions are invited, and should be forwarded to the Thermal Spray Society of ASM International®.

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1. SCOPE

The scope of this document discusses the safety issues associated with the design and operation of thermal spray booths and boxes. The document's scope is limited to thermal spray booth or spray box structures and the equipment, or systems – internal and external – required to operate the thermal spray processes within these enclosures. This includes the mitigation of sound, dust and fume, ultraviolet light, and mechanical (robotics) hazards that must be contained or controlled by a properly designed and properly used enclosure. This document does not cover the Personal Protective Equipment (PPE) needs of any operator that may enter the booth before or after the process is active. It addresses only the design of spray booths that allow normal operation of the process from outside the booth itself (sometimes referred to as a “closed system”). This document does not address manual operation of the process with the operator inside the booth itself. The document does not cover vacuum plasma spray (VPS) chambers because they are substantially different from atmospheric enclosures in their design, operation and safety considerations.

These guidelines are written within the context of the prevailing internationally accepted practices and standards, as well as United States laws and regulations. They are intended to have worldwide application. It is incumbent upon each individual, company, or institution referencing these guidelines, to ensure compliance with all relevant local country/community laws, rules and regulations, and to apply generally accepted, good engineering practice to the design, fabrication, and installation of thermal spray systems that are safe, reliable, and legal.

Thermal Spray booth design is complex and involves many different engineering disciplines. Because of the diverse nature of thermal spray process requirements, this document alone cannot provide all the information needed for booth design. Suppliers/professionals with expertise in specific aspects of booth design (ventilation, sound suppression, piping, etc.) should be consulted to ensure design safety and integrity.

This guideline is intended for use in conjunction with the other reference publications, local publications, and applicable standards. An extensive, but not comprehensive, list of these is included in Section 4, *RELATED STANDARDS AND DOCUMENTS*

2. OVERVIEW

The primary role of a thermal spray enclosure is to contain and/or control various hazards associated with thermal spray processing of materials. Historically, thermal spray booths were used to shield the shop floor from the intense sound pressures, dust and fumes, and ultraviolet light generated during spray operations. In the past decade, the introduction of robotics has led to an expanded role for booths as barriers to protect humans from being struck by fast-moving robotic arms. The most modern spray enclosures are now designed to minimize operator exposure to a variety of thermal spray hazards. Spray boxes and fully automated spray booths that do not require an operator to be present in the spray environment are becoming more common, and in many situations have become an accepted requirement.

The use of an enclosed space to reduce hazards has considerably increased the safety of thermal spray operators and shop personnel that work in the vicinity of thermal spray devices. However, an enclosure introduces new hazards that must be dealt with. A wide variety of gases are used in thermal spray processing. Unless proper care is taken, it is possible to create dangerous situations within an enclosure. An inert gas leak can displace the air, leading to an asphyxiation hazard. A fuel leak or build-up of an explosive metal powder can set up the possibility of a violent explosion. Thermal spray enclosures must be designed to provide simple egress of operators during an emergency situation. Operators inside a spray booth may be unaware of emergency situations on the shop floor, such as fire alarms, unless special provisions are made.

The thermal spray enclosure is the most important safety device used in thermal spray processing. Because the spray operations are conducted within its confines, all of the energy sources (gas, electricity, and water), the feedstock materials, and all of the process effluents (heat, dust, fumes, sound and ultraviolet light) are present. Proper mitigation of all of these hazards requires careful thought in the design and operation of a spray booth.

3. SPECIAL TERMINOLOGY USED WITHIN THIS GUIDELINE

Within this document, distinct terminology is employed to differentiate between ***Requirements***, ***Recommendations***, and ***Considerations***. The meanings of these terms in any word form are defined below and wherever these terms are used in these guidelines in the context of a safety practice, they are presented in ***bold italic*** typeface.

A ***Requirement*** is a safety practice that *must* be conformed to at any thermal spray facility. Typically a requirement is already an industry-accepted or government-regulated practice about which there is little or no debate regarding the importance of its safety-related issues, and the methods by which identified hazards are mitigated. An example of a ***Requirement*** would be that the piping used to carry acetylene may not be fabricated from alloys that contain more than 65% by weight of copper or other identified reactive constituents. It is well known that the use of copper tubing for carrying acetylene is very dangerous, due to the formation of unstable compounds, and it is difficult to imagine any thermal spray installation in which copper tubing is acceptable for carrying acetylene.

A ***Recommendation*** is applied to a safety practice that *should* be carefully considered before a reader chooses to ignore it. Recommendations should not be dismissed lightly. There may be certain situations in which a recommendation can be ignored, but in general, most thermal spray facilities should implement all recommendations. An example of a ***Recommendation*** would be the installation of a manual shutoff valve (Station Outlet valve) for each gas at each spray booth in a facility. There may be situations in which installing this valve is not appropriate; however, before deciding to ignore this recommendation, the thermal spray facility designer should carefully think through how isolating the gases from an individual booth would be accomplished, if necessary.

A ***Consideration*** is a safety practice that *may* be contemplated for implementation at a thermal spray facility. Considerations are safety enhancements that may not be essential or applicable to all situations. An example of a ***Consideration*** would be the installation of an oxygen or combustible gas monitor in a spray booth, the purpose of which is to detect the formation of a dangerous atmosphere. The ability to detect an asphyxiating or combustible atmosphere is a measure that improves safety. However, these sensors are prone to failure, and can be expensive to install and maintain. By properly designing a booth with various interlocked solenoid valves and natural ventilation, the possibility of forming a dangerous atmosphere can be reduced to the point that monitors do not provide a substantial increase in safety.

4. RELATED STANDARDS AND DOCUMENTS

Where standards and other documents are referenced in this publication, they refer to the latest edition.

U.S. Standards		
Publication	Title	Available from:
ASTM Publications:		American Society for Testing and Materials 100 Bar Harbor Drive West Conshohocken, PA 19428-2959 www.astm.org
A53	<i>Specification for Pipe, Steel Black and Hot-Dipped, Zinc-Coated Welded and Seamless</i>	
A105	<i>Specification for Forgings, Carbon Steel, and Piping Components</i>	
A106	<i>Specification for Seamless Carbon Steel Pipe for High-Temperature Service</i>	
A182	<i>Specification for Forged or Rolled Alloy Steel Pipe Flanges, Forged Fittings and Valves and Parts for High Temperatures</i>	
A312	<i>Specifications for Seamless and Welded Austenitic Stainless Steel Pipes</i>	
E-84	<i>Surface Burning Characteristics of Building Materials</i>	
E-447	<i>Compressive Strength of Laboratory Constructed Masonry Prisms</i>	
CGA Publications:		The Compressed Gas Association 1235 Jefferson Davis Highway Arlington, VA 22202 www.cganet.com
G-1	<i>Acetylene</i>	
G-1.3	<i>Acetylene Transmission for Chemical Synthesis</i>	
G-4	<i>Oxygen</i>	
G-4.1	<i>Cleaning Equipment for Oxygen Service</i>	
G-4.4	<i>Industrial Practices for Gaseous Oxygen Transmission and Distribution Piping Systems</i>	
ANSI Publications:		American National Standards Institute 1430 Broadway New York, NY 10018 www.ansi.org
ANSI/ASME B31.3	<i>Chemical Plant and Petroleum Refinery Piping</i>	
A 13.1	<i>Scheme for Identification of Piping</i>	
R15.06	<i>Safety Procedures for Industrial Robots and Robot Systems</i>	

Publication	Title	Available from:
EPA Publications	<i>Industrial Ventilation, 23rd edition, 1998</i>	U.S. Environmental Protection Agency Ariel Rose Bldg. 1200 Pennsylvania Ave., N.W. Mail Code 3213A Washington D.C. 20460 www.epa.gov
NFPA Publications:	<i>Sprinkler Systems</i>	National Fire Protection Assoc. Battery March Park Quincy, MA 02269 www.nfpa.org
13		
51	<i>Design and Installation of Oxygen-Fuel Gas Systems for Welding, Cutting and Allied Processes</i>	
68	<i>Explosion Deflagrations (Venting)</i>	
69	<i>Explosion Prevention Systems</i>	
70	<i>National Electric Code, Article 500, Hazardous Locations</i>	
255	<i>Std. Method of Test of Surface Burning Characterizations of Building Materials</i>	
484	<i>Combustible Metals, Metal Powders, and Metal Dusts.</i>	
496	<i>Purged and Pressurized Enclosures for Electrical Equipment</i>	
497M	<i>Classification of Gases, Vapors, Dusts for Electrical Equipment in Hazardous Locations</i>	
TSS Publications:	<i>Safety Guidelines for the Handling and Use of Gases in Thermal Spraying</i>	ASM International® 9639 Kinsman Road Materials Park, OH 44073-0002 www.asminternational.org
SG001-02		
SG002-02	<i>Safety Guidelines for Performing Risk Assessments</i>	
OSHA Publications		Occupational Safety and Health Administration 1-800-321-OSHA for nearest location www.osha.gov
SMACNA	<i>SMACNA HVAC Duct Construction Standards – Metal and Flexible</i>	SMACNA, Inc. 4201 Lafayette Center Dr. Chantilly, VA 22021 Ph. 703-803-2980; Fax: 703-803-3732

INTERNATIONAL STANDARDS		
Publication	Title	Available from:
EN ISO 2063	Thermal spraying -- Metallic and other inorganic coatings -- Zinc, aluminium and their alloys	International Organization For Standardization 1, rue de Varembé, CH-1211 Geneva 20, Switzerland <i>Phone</i> +41 22 749 01 11 <i>Fax</i> +41 22 749 09 47 <i>E-mail</i> sales@iso.org
EN ISO 14231	Acceptance inspection of thermal spraying equipment	
EN ISO 14232	Powders -- Composition and technical supply conditions	
EN ISO 14917	Thermal spraying – Terminology, classification	

5. TERMINOLOGY/DEFINITIONS

ACGIH – American Council of Industrial Hygienists.

Administrative Controls – Reducing the risk of injury through management of the processes and workforce.

ANSI – An abbreviation for American National Standards Institute.

ASTM – An abbreviation for American Society for Testing and Materials.

AWS – An abbreviation for the American Welding Society.

Approved – Acceptable to the authority having jurisdiction.

Branch Lines – The piping that leads from the Main pipeline to Station Outlet Valves supplying the Process equipment.

CGA – An abbreviation for the Compressed Gas Association.

Detonation Gun – A thermal spray device that employs rapid detonation of an oxygen-fuel mixture to heat and carry coating powders to the surface of a part in order to apply a coating that enhances the part's surface performance properties.

Dead Air – Areas where there is little or no air motion such that dust or particulates in the air will fall and accumulate on the booth interior surfaces.

Decibel (dB) – A numerical expression of the relative loudness, or intensity, of a sound. The difference in decibels between two sounds is ten times the logarithm of the ratio of their power levels. The "A" suffix when used with dB (dBA) signifies a non-linear averaging of noise levels across ten octave bands to compensate for human ear sensitivity to sound at various frequencies.

De-ionized Water – Water from which nearly all ions (electrically charged particles) have been removed returning it to its purest state to minimize corrosion, or other chemical reactions. Often required or recommended by manufacturers for cooling water.

Design Pressure – The same as *Maximum Allowable Working Pressure* referenced in many codes. This pressure is typically at least 15% higher than system Operating Pressure,

Dry Ice (CO₂ Snow) – the solid state of carbon dioxide. Usually forms when a sudden pressure release of CO₂ occurs such as spraying.

Effluent – A term used to encompass all the gases, coating, fumes, etc. emitted from a thermal spray gun or torch.

Enclosure – The cabinet or housing of apparatus or the fence or wall surrounding an installation to prevent personnel from personal injury hazards or to protect the equipment from physical damage.

Engineering Controls – Reducing the risk or potential for injury by incorporating safety systems, features, interlocks, etc. into the design of machines, tools, layouts and processes.

EPA – abbreviation used for the Environmental Protection Agency (USA).

Equipment - A general term including materials, fittings, devices, appliances, fixtures, apparatus and the like used as a part of, or in connection with, a thermal spray installation.

Ergonomics – The process or science of adapting workstations, tools, equipment and work techniques to be compatible with human anatomy and physiology so as to reduce the risk of injury due to occupational activity or stresses.

Fuel Gas – Any combustible gas, including hydrogen, propane, propylene, acetylene, MAPP, etc. used in a thermal spray process.

Fuse – An over-current protective device incorporating a fusible component or link that is heated by excessive current flow and subsequently separates, or opens, halting the flow of current. A fuse is typically not reusable.

Fumes – Particulate matter consisting of particles generated by the condensation of gases created by evaporation of melted substances.

Frequency – The number of cycles-per-second of a device, signal, or parameter. Generally expressed in Hertz (Hz).

Ground Fault (Circuit) Interrupter (GFI or GFCI) – A protection device designed to remove the electrical power from a circuit when an imbalance of current exists between the supply conductor and the return conductor indicating the presence of a leakage fault path, usually to ground or earth. Such a fault path could be a result of malfunctioning or damaged equipment. For example: water leaks and subsequent corrosion, or contact with tools or personnel. Early detection of faults and disconnection of power by a GFI device can often avoid or minimize damage or injury.

HEPA – An abbreviation used for High Efficiency Particulate Air. In reference to air filters, it specifies that 99.97% of particles larger than 0.3 micron will be removed from the air stream.

HVOF – High Velocity Oxygen Fuel. This type of high velocity coating process uses a liquid or gaseous fuel combusted with oxygen to heat and carry coating material to the surface of a part in order to enhance the part's surface performance properties.

HVAF – High Velocity Air Fuel. This type of high velocity coating process uses a gaseous fuel with air to heat and carry coating material to the surface of a part to enhance its surface features.

Interlock – A switch or other device that prevents the activation of a piece of equipment when a protective door is open or other hazards exist.

LPPS – Low Pressure Plasma Spray. See preferred term Vacuum Plasma Spray Deposition.

Lock-out/Tag-out – The process of locking and tagging any energy source (typically a valve or electrical shutoff) to isolate sources of energy during maintenance/repair and prevent inadvertent operation – or release of energy or hazardous material.

Main Piping – That portion of a gas piping system that leads from a gas supply source to the branch piping.

MSDS – An abbreviation used for Material Safety Data Sheets.

Negative Pressure – An area or volume, such as the interior of a spray booth, which is at a lower pressure than the surrounding area..

NFPA (National Fire Protection Association) – A U.S. based organization providing advisory standards offered for use in law and for regulatory purposes in the interest of life and property protection.

NIOSH – National Institute for Safety and Health

Noise - Unwanted sound which may be hazardous to health, interferes with communications, or is disturbing.

Operating Pressure – The pressure at which a system normally operates; not the pressure to which a system may be subjected to during upset, or unusual circumstances. At the inlet to the piping system, the Operating Pressure equals the Supply Pressure. The Operating Pressure in a portion, or all, of a piping system may be reduced with a pressure regulator (pressure reducing valve).

OSHA – Occupational Safety and Health Administration (USA).

Permissible Exposure Limit (PEL) – is the maximum amount or concentration of a chemical that a worker may be exposed to under OSHA regulations.

Piping – The parts of a fluid/gas system that consist of conduits in the form of rigid pipes, tubing (flexible), interconnecting fittings, and in-line accessories.

Process Equipment – The mechanical and/or electrical devices and associated control systems that are used to produce coatings or produce surface enhancements, and whose operation directly affects the chemistry, or the physical properties, of the final product. Typically, this includes gas consoles, regulator panels, hose bundles, powder feeders, gases and gas supplies, and the thermal spray gun or torch.

Purging – The process of admitting an inert gas into one end of a pipeline or container and venting the other end for a specific period of time. Used to remove (purge) hazardous or combustible materials from the pipeline or container.

PVC – (Polyvinyl Chloride) – A type of material commonly called plastic pipe. It is used for its corrosion resistance and ease of fabrication, but usually has lower impact resistance and pressure ratings as compared to metal piping.

RIA – Robotic Industry Association. A co-publisher, with ANSI, of robot safety standards.

REL (Recommended Exposure Limit) – An 8 or 10-hour time-weighted average (TWA) or ceiling (C) exposure concentration recommended by NIOSH that is based on an evaluation of health effects data.

Safeguarded Space – Shielded, fenced, covered, enclosed or otherwise protected by means of suitable covers, casings or barriers to remove the likelihood of unsafe approach.

SMACNA – Sheet Metal and Air Conditioning Contractors National Association.

Sound – A vibrational disturbance, exciting hearing mechanisms, transmitted in a predictable manner determined by the medium through which it propagates.

Sound Pressure – Fluctuations in air pressure caused by the presence of sound waves.

Sound Pressure Level - The intensity of a sound, expressed in decibels (dB).

Spray Booth – An enclosure for thermal spray processes that is specifically designed to mitigate process hazards. A spray booth is NOT designed for human occupancy during routine spray operations; however, it is routinely occupied for maintenance and process setup.

Spray (Coating) Box – A spray (coating) box is an enclosure for thermal spray processes that is specifically designed to mitigate process hazards. These boxes are NOT designed for human occupancy during routine spray operations, process setup and routine maintenance.

Spray Enclosure – A term used in this document whenever a statement is equally applicable to either a spray booth or a spray (coating) box.

Station Outlet Valve – The shut-off valve located at the downstream end of the branch piping or the point at which process equipment is connected to the piping system.

Test Pressure – The pressure to which devices/piping are subjected for design testing purposes. Typically this pressure is 1.3 to 1.5 times greater than the Operating Pressure for pressure vessels; often many times greater for piping.

Threshold Limit Value (TLV) – are guidelines prepared by the *American Conference of Governmental Industrial Hygienists, Inc (ACGIH)* to assist in making decisions regarding safe levels of exposure to various hazards found in the workplace. A TLV reflects the level of exposure that the typical worker can experience without an unreasonable risk of disease or injury.

Turbulent Flow – Flow of air that is not uniformly distributed over a cross section of a pipe, tube or hose, resulting in unpredictable eddies, vortices, back-flow, and areas where little movement of air occurs.

Vacuum Plasma Deposition (VPD) – A thermal spraying process variation utilizing a plasma gun confined to a solid enclosure. The enclosure is evacuated and the spraying performed under low pressure, also known as Vacuum Plasma Spray (VPS), Low Pressure Plasma Spray (LPPS[®]).

Ventilation System – A complete air handling and filtration system for a thermal spray booth from the intake of air into the process to the exhaust of the air back into the atmosphere. In this document, the spray booth is considered as part of the exhaust system in regard to air flow.

6. BOOTH STRUCTURE AND SOUND SUPPRESSION

6.1. Scope

This section on Booth Structure and Sound Suppression provides information intended to promote increased safety awareness in the design and configuration of basic booth enclosures for thermal spray installations.

The focus of this section is on the key elements of booth structure and how structure and configuration issues impact the safety of operators and employees. The structure of a typical thermal spray booth has the primary function of controlling exposure to the following major hazards:

- Excessive sound levels
- Powder / dust from the process
- Gases / Fumes
- Visible light and ultraviolet (U.V.) radiation

The configuration of a typical thermal spray cell, in most cases, centers on an enclosure structure that works with other sub-systems (interlocks, controls, ventilation/ filtration, etc.) to provide effective control and protection from these major hazards.

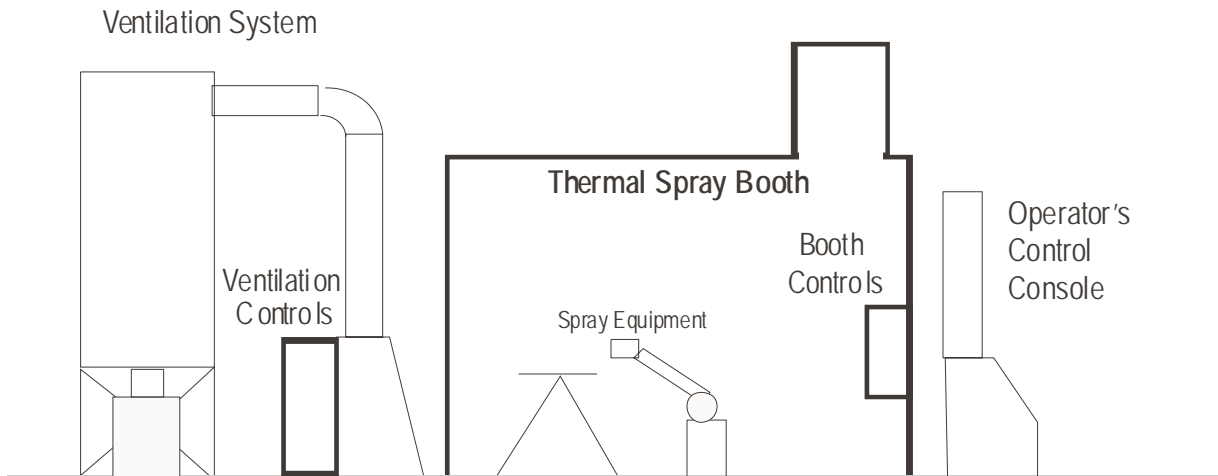


Figure 6-1. Typical Thermal Spray Booth Configuration

6.2. Configuration

Typical thermal spray installations include an enclosure that protects the operator and the surrounding areas from the hazards associated with the thermal spray process while it is in operation. There are three main types of enclosures used to contain the process and allow its operator to remain outside its confines:

Walk-in style booth – A Walk-in booth consists of an enclosure that surrounds the process, the part, and the gun or torch manipulating equipment in such a manner that the operator need *not* be present in the booth during normal operation. The operator or other personnel are typically in the booth for job setup and routine maintenance of the equipment, but operation of the process, and the manipulating equipment used to perform the actual thermal spray coating, may be initiated remotely only by the operator with controls located outside of the booth. Interlocks between gases, the process, ventilation, and operator entry are designed accordingly.

This style of thermal spray booth is the most common type. This is largely due to its flexibility to accept components, fixtures and equipment with considerable variation in size and configuration with minimal modification and associated costs. Such a configuration, with proper interlocks and safety systems, can satisfactorily limit the exposure of the operator and other personnel to the major hazards associated with thermal spray process and support equipment.

Spray (Coating) box – A Spray box has its enclosure closely fitted to the thermal spray device and part manipulation equipment. This arrangement allows the operator to load parts for coating through a door while the process is shut off, and never requires entry onto the area where coating takes place. Such an arrangement affords maximum efficiency for dust collection (smallest ventilated volume) and provides the greatest operator safety. Eliminating the need to enter the confines of the spray box provides the maximum level of protection from exposure to particulate matter, fumes, gases, noise, and radiation as well as improved protection from moving mechanical components.

Thru-the-Wall booth – Either of the above types can be configured to allow the passing of parts through a port or load-lock while the process is in operation, often providing higher productivity than other configurations. Proper design must be followed to limit operator exposure to the major hazards of sound, radiation, or dust. Additionally, care must be taken to properly interlock manipulation equipment operation to protect the operator from potential pinch/crush points associated with the door.

Both the Spray box and Thru-the-Wall booth designs see limited application because of reduced flexibility to changing needs and resultant increased costs of tooling. Both types share many of the same design requirements of the Walk-in style booth but typically differ considerably in the area of interlocking.

6.3. General Construction

Construction of the basic booth (wall, ceilings, door panels, etc.) must meet the sound attenuation requirements for the specific process in use. Typically, materials that meet sound attenuation requirements easily meet radiation (thermal/visible/UV) and dust control requirements. Thermal spray booth construction is most often of modular acoustical panels or, in some cases, of conventional block and mortar construction.

Modular construction - This construction method typically comprises sheet steel panels filled with a form of non-flammable insulation such as fiberglass. The panels typically consist of solid steel sheet on one side and perforated metal on the other. The enclosure is normally constructed with the perforated side of the panels toward the sound source.

Block and Mortar – This construction method is rarely used today due to economic constraints and lack of portability. However, this method of construction can easily meet basic safety requirements for operator protection.

General Requirements

Non-flammable – The nature of the thermal spray process **requires** that general booth construction materials be non-flammable.

Sound Suppression – The design and construction of the booth is the single most significant factor determining the attenuation of sound associated with the thermal spray process. It is **required** that sound be attenuated to acceptable levels as dictated by local codes and standards to ensure operator protection. Additional information on this topic can be found in Section 7.5.

Access Doors / Windows

Design and construction of booth doors are critical to providing adequate sound suppression and operator protection from powders, dusts, gases, fumes, and UV radiation.

It is **required** that doors be provided with positive latches, hinges and seals that ensure continued protection of personnel from the above hazards.

The weight of the door, its frequency of access, and difficulty of operation should be **considerations** in determining whether the door should be mechanized.

It is **required** that observation windows be constructed of multi-layered transparent plastic material or tempered glass for breakage resistance and safety. Windows employed in spray booths using plasma or wire arc spray processes **require** the appropriate level of shading for UV protection. This may be a roll-up style shade. A prominently displayed warning sign is **required** advising of the dangers of UV exposure.

Booth Wall and Ceiling Penetrations

Penetrations, or openings, through sound control walls are a necessary conduit for electrical cables and gas and/or water hoses and pipes. Suitable sound absorbent materials are typically used to control the sound conducted and radiated through such openings. It is **required** that all openings be sealed to minimize sound leakage and maintain an adequate seal against powder / dust leakage.

Penetrations through typical panels are **required** to be lined such that hoses and cables are not exposed to sharp edges.

Booth Ceilings / Roofs

Often the ceiling or roof area of a thermal spray booth is utilized as a location for the mounting of equipment such as fans, power sources, and filtration equipment. Additionally, the ceiling inside of a booth is often required to support small hanging hoists and/or other parts handling devices. Sound insulation panels are often of lightweight construction that needs adequate reinforcement to meet equipment support needs. Adherence to all local building codes for such areas is **required**.

The typical thermal spray cell ceiling, or roof, is primarily designed for sound control, and as such is typically not designed for carrying loads. It is **recommended** that due consideration be given to the design load capacity of the ceiling/roof of the thermal spray booth if these surfaces and areas are to be used for mounting and storage.

Consideration should be given to:

- Proper reinforcement for the mounting of all hoists and other part-handling devices.
- Appropriate reinforcement of roof areas to properly support mounted equipment.
- Adequate walk areas to facilitate safe servicing of equipment.
- Railings, toe boards, and other appropriate fall-protection devices to ensure that the top of the booth is a safe workplace. Openings in the railing must be chained or gated.
- Ladders or stairs to provide easy and safe access to the booth roof area.
- Suspension of heavy items from the facility roof to avoid load on the cubicle.

Booth Cleaning

Consideration should be given to regular cleaning of the interior of a thermal spray booth. The frequency of cleaning requirements depends on the process type, coating material type, part configuration and vent system design.

Since many thermal spray powders are considered hazardous materials, often the safest cleaning method is a HEPA vacuum cleaner. In some cases, washing of floors and/or walls may be necessary. In many cases, the waste cleaning liquid will be considered hazardous waste and will **require** handling that complies with local regulations.

Typical perforated sound panels become impregnated with thermal spray particulate over years of booth operation. Although this does not seem to affect sound absorption performance, washing of such used panels with liquid presents unique problems and should be avoided. In addition, used panels, when shipped or disposed of, often must be categorized as hazardous waste.

6.4. Sound Hazards and Control

Noise and Noise Level

Noise is defined as an unneeded and objectionable sound. Excessive noise, common to most all thermal spray devices, can reduce productivity, slow reaction times, and can cause tension, hearing impairment, and nervousness.

The Occupational Safety and Health Administration (OSHA) and similar organizations worldwide **require** employers to provide safe working conditions. These organizations typically do not provide guidelines specific to an industry or process but they do establish general rules for the control of unsafe and unhealthy conditions.

Noise level is a measurement of sound wave energy (pressure). The standard unit of sound measurement is decibels (dB). The use of the decibel, a unit based on the logarithm of the sound intensity power, provides a scale that better represents how loud the sound or noise is perceived by a typical human.

Typical Sound Power Levels of Various Sources

Source	Sound Power, Watts	Decibel, dBA
Saturn Rocket	100,000,000	200
Afterburner, Jet Engine	100,000	170
75 Piece Orchestra	10	130
Centrifugal Fan at 13,000 cfm	0.1	110
Automobile on Highway	0.01	100
Food Blender	0.001	90
Dishwasher	0.0001	80
Voice, Normal Conversation Level	0.00001	70
Duct Silencer, self noise at 1,000 fpm	0.00000001	40
Quietest Audible Sound	0.000000000001	0

Typical Thermal Spray Noise Levels / Noise duration tolerance

Thermal spray processes generate high noise levels. The following table shows typical noise levels of various processes. Parameter settings and coating types have significant impact on overall sound levels.

Thermal Spray Device	Decibel, dBA
Detonation gun	145
HVOF liquid fuel	133
HVOF gaseous fuel	125 - 135
HVAF	133
Wire Flame Spray	118-122
Powder Flame Spray	90-125
Rod Flame Spray Gun	125
Electric Arc	105-119
Air Plasma Spray (APS)	110-125
Vacuum Plasma Deposition (VPD)/LPPS [®]	Ambient ¹
Cold Spray	110
Water Stabilized Plasma	125
RF Plasma	95

The table below shows typically accepted tolerable noise limits for various exposure times: the louder the noise level present, the shorter the permissible exposure time.

Tolerable Noise Limits of Various Exposure Times (Source NIOSH – ACGIH)	
Exposure Duration (Per Day)	Sound Level (dBA)
Hours	
16	82
8	85*
4	88
2	91
1	94
Minutes	
30	97
15	100
7.5	103
2	109

* OSHA Requirements state that any exposure over this level **requires** hearing protection.

Typical Booth Acoustical Construction

¹ Some processes, such as VPS (also known as Low Pressure Plasma Spray, or LPPS[®]), are carried out within a vacuum chamber that takes the place of a conventional acoustic enclosure. In many instances, noise from the main process is attenuated beyond the point of being any concern. However, in many cases, continuous noise from pumps, fans and other ancillary equipment is at such a level that steps must be taken to protect personnel appropriately.

Modular construction typically will consist of panels approximately 4 inches (102 mm) in thickness with sheet metal inner and outer walls packed with a sound absorbent material such as fiberglass. More often the inner panel is perforated to better allow the acoustic energy to enter and thus dissipate within the absorbent material. It is common for plasma, electric arc, and HVOF devices to utilize single-walled booths while the lower frequency sound signatures associated with detonation devices typically will **require** double-walled booths often with heavier mass sound absorbent materials.

Typically, the supplier of the acoustic enclosure can provide access door and window designs to suit the needs of the installation. It is critical that door seals remain tight and receive regular maintenance attention such that the full acoustic effectiveness of the enclosure can be maintained. Particular attention needs to be given to windows, seals around windows and wall penetrations, seals against the floor, sound reflections of building ceilings, etc.

Numerous alternative solutions can provide good performance for thermal spray processes. Consult with the supplier of the thermal spray device or similar devices to obtain the best advice on solutions for specific acoustic spray booth application and configurations.

Exposure Control

In most situations, it is the employer that has the ultimate responsibility for protecting employees from excessive noise. In the case of new equipment construction, be sure that the vendor provides adequate noise control and that the proper tests are conducted during equipment acceptance to ensure compliance with local safety and health regulations.

Used equipment can often present difficult problems if the appropriate noise control qualities are not designed into the equipment. Given a specific equipment design, certain engineering, administrative and personal protective schemes may help. Some examples are:

Work Area Isolation

Increasing the distance between the noise source and the employee lowers the sound pressure level. The following table lists how increasing distance can reduce decibels in a free field.

Using Distance to Reduce Decibels	
Distance from Source	Theoretical dBA Reduction
3 feet (1 m)	0
10 feet (3 m)	10
30 feet (9 m)	20
90 feet (27 m)	28

Blocking the path of sound transmission by adding sound absorbing materials to the work area will provide significant noise reduction. Consult noise control experts for material recommendations. Noise may also be isolated by moving its source away from affected personnel or placing the equipment in an acoustically insulated enclosure. Often adding insulation to an existing enclosure can provide additional attenuation.

Plan and Schedule to Reduce Exposure Time

Engineering controls focus on eliminating, reducing, or containing the noise hazard. Administrative controls attempt to reduce exposure time.

Planning and scheduling are best used where spraying is intermittent. Usually, spraying time is a small percentage of the total job compared with setup, surface preparation, and finishing.

If spraying time exceeds the permissible levels for noise exposure, schedule jobs over more than one shift or day to keep exposure within maximum limits. More than one operator can spray jobs to keep the exposure of any one person within limits. Spraying outside of regular plant hours can control exposure of persons near the operation. Also, rotate personnel assignments in the vicinity of the thermal spraying operation to control exposure.

Use of Personal Protective Equipment (PPE)

If generally accepted or local regulatory requirements cannot be met regarding sound exposure, it is **required** that employers supply and mandate the use of appropriate personal protective equipment.

6.5. Powder and Dust Control

Powder and dust control are mainly provided by the ventilation/filtration system discussed in Section 8; however, some issues are more specifically related to booth structure and controls and as such are deserving of coverage here:

Integrated Design

The booth design needs to be linked with good ventilation flow and control. Often, the early design selections regarding booth or coating box layout can have a major impact on the ability to establish good ventilation flow and the ability to carry waste powder to the filtration system. Specific ventilation areas impacted by booth layout are:

Total air flow and local velocities – Booth layout will affect total air flow capability and will determine local velocities. Local air velocities will have a significant impact on the ability of the system to capture dust particles and carry them into the ductwork leading to the filters rather than having them settle and accumulate on the booth floor, walls and tooling.

Laminar flow – The smoothest possible flow of air is very beneficial to the effective removal of dust from the process area carrying it into the ducts leading to the filters. Turbulent flow often will create eddies and low pressure areas that cause dust to be trapped or dropped from the air stream. Necessary and sometimes unnecessary booth obstacles such as tooling, parts to be sprayed, robots, and fixtures in practice detract from smooth air flow however steps can still be taken to maximize performance for any given installation.

Negative Pressure – Exhaust fans, inlet fans (if so equipped) and dampers should be adjusted such that a slight negative pressure is maintained within the thermal spray booth when closed and operating. Typical booths are not completely airtight. The effect of a slight negative pressure is that small leaks are in an inward direction carrying dust to the interior and the filters rather than leaks in an outward direction that carry dust and fumes into the shop areas.

Entry Timer – A timer should be considered to prevent entry into the booth until a preset time has elapsed after the shutdown of the process. This allows the ventilation system to clear the air of hazardous dust.

Important: *A spray booth with poor ventilation or one that allows entry before the ventilation flow can adequately remove airborne dust particles may result in unacceptable exposure of entering personnel to dust inhalation hazards. If entry is required, appropriate PPE must be worn.*

6.6. Radiation Control

Typical thermal spray processes radiate energy in both electromagnetic and acoustic forms. Emission of sound (acoustic) energy and its control are adequately covered elsewhere in this document. Electromagnetic radiation associated with thermal spray processes is typically divided into two classes. Such radiation can occur in the visible (or near visible) range and also as un-wanted electromagnetic radiation in the power and radio frequency portions of the electromagnetic spectrum.

Ultraviolet, Bright Visible, and Infrared Radiation are common when using thermal spray devices and certain precautions are **required** in order to adequately protect employees from their effects. Typically direct effects will include temporary and/or permanent damage to the eyes as well as burns to the skin.

Electromagnetic Radiation can take the form of unwanted radio-frequency (RF) waves capable of transmission through the air or along wiring, piping and metal based construction materials. At levels commonly associated with thermal spray devices, it is not likely that RF radiation can approach the levels necessary to cause injury (such as might be experienced in a microwave oven). However, radiated RF energy from machinery (especially thermal spray equipment using electric arcs and arc starters) can cause malfunctions of other equipment which, in turn, could have serious affects on the health and well-being of personnel in the area. Steps are often **required** to minimize such radiation and ensure the posting of warnings announcing its presence.

Protection - Ultraviolet, bright visible and infrared radiation

Increasing distance from a radiation source has a considerable effect on the energy level and thus the resultant hazard to personnel. A typical properly interlocked thermal spray booth affords some protection for the operator in that it prevents close observation such as might be an issue with a process such as manual welding.

Arc burns and permanent eye damage can still occur from exposure to the radiation from plasma, electric arc, and some flame processes through windows in the spray booth wall. Proper use of tinted glass and/or pull-down shades can prevent such injuries. A protection scheme suited to the specific process and booth configuration is **required**. Consult with the manufacturer of the thermal spray process equipment to determine what steps are appropriate and in keeping with locally established regulations.

Protection – Electromagnetic radiation

Electromagnetic radiation from thermal spray process, also known as EMI/RFI, is most often the result of electric-arc-based processes (electric arc spray, DC and RF plasma). Substantial electric currents in gun cables and ground paths as well as in high-frequency arc starting circuitry are often the cause. Shielding of high-current cables, although effective, is often not possible due to performance degradation.

The problem is often best controlled by arranging equipment such that gun-to-power source electrical cables are the shortest length possible. Also high frequency arc starter assemblies should be located as close to the process gun as possible. Cables such as these can behave as radio frequency transmitting antennae and need to be kept as short as possible. Also, if such process power cables are run parallel and close to metal conductors such as pipes, structural supports, other cables, etc. transmission and re-radiation can occur. These **recommendations** will minimize radiation and control potentially hazardous effects.

Equipment marketed in Europe is now **required** to meet the EMC (Electromagnetic Compatibility) Directive. This unified European directive **requires** that machinery pass tests regarding emission of electromagnetic radiation as well as tests verifying the equipment's resistance to radiation from other equipment.

The equipment supplier is the best source of information regarding radiation and adequate protection from it as well as the appropriate posted warnings that may be **required** by local codes.

6.7. Safety Interlocks

Safety Interlocks should be incorporated into any good thermal spray booth layout. Such interlocks provide protection from hazards by techniques including, but not limited to: removing power, preventing entry, limiting equipment travel, starting a fan, sounding a warning and the like.

The following is a listing of *some* typical interlocks used to mitigate hazards associated with thermal spray processes that provide the necessary level of safety in relation to that hazard. *Note: This cannot be a complete list as the hazards are as many as there are variations in booth configuration. Completing a design review and a risk analysis is **recommended** to help identify hazards and thus ensure the appropriate steps are taken to reduce those hazards. In many cases local codes and/or laws **require** such attention.*

Access Door Interlocks – Switches that **require** doors to be fully closed to enable process start, and stop the process if opened during operation.

Electrical cabinet Interlocks – Typically remove internal power when a cabinet is opened and are often **required**.

Emergency Stop – Typically push to lock – pull to release button(s) provided to remove power (as appropriate) in an emergency. It is highly **recommended** that all E-stop buttons in a spray system perform the same function.

Gas Interlocks – Used to block gas flows under certain conditions in addition to problems with lack of ventilation.

Lock-out/Tag-out – System shutoff means are **required** to allow all energy sources to be disconnected and isolated from the thermal spray system or cell. Such shutoff devices must be equipped to accept a lockout device and associated tag to prevent accidental re-energizing of the equipment and subsequent exposure of personnel to hazards

Power interlocks – Used to prevent power application unless certain conditions are met.

Presence sensing switches – Often used to ensure the operator is in a safe position during an activity.

Travel limit switches – Used to protect personnel and hardware from equipment over-travel.

Travel speed limit interlock – Used to limit robot speeds during teach mode and is **required**.

Ventilation/Gas flow interlock – It is **recommended** that all spray equipment should have appropriate interlocks to prevent operation unless there is adequate ventilation flow. It is also **required** that all fuel gas lines entering a spray booth be interlocked to ensure adequate ventilation flow is detected prior to enabling process gas flow.

Ventilation/Spray Booth access – To ensure time for the booth atmosphere clearance, it is **recommended** that cubicle access be interlocked by a timer that requires ventilation flow to continue for a specific time after the process is stopped before allowing cubicle entry.

Local codes and regulations have much to say regarding interlocks and how they are to be implemented. It is **recommended** that the equipment supplier be consulted to ensure compliance with local **requirements**.

6.8. Warning / labeling

As is the case with all industrial equipment thermal spray equipment, warning labeling is **required** to ensure that employees are aware of the associated hazards and the steps and/or equipment required to allow them to perform their job in a safe manner.

The following list represents some examples of hazards normally found in thermal spray installations that may require labeling:

- Metal powders and associated dangers of inhalation and ingestion
- Gaseous and volatile substances or other chemical by-products
- High velocity ventilation systems
- Robot arms
- Doors and other mechanisms
- High voltage/high frequency ignition systems
- Combustible gases
- High current DC power sources
- Ultraviolet and/or infrared radiation
- High intensity noise
- Pressurized powder feeders

Local codes and regulations again have much to say regarding the proper use of warning labels. The European Union countries **require** labeling in the native language of the country where the equipment is used. It is **recommended** that the equipment supplier be consulted regarding compliance with local **requirements** regarding this subject.

6.9. Maintenance Issues (Safety Related)

Preventive Maintenance (PM) of thermal spray equipment, as with any piece of complex industrial equipment, will directly impact efficiency and reliability of the installation as well as the quality of the coatings produced. Even more importantly, many maintenance requirements and procedures have a direct impact on safe operation and the safety of the employees operating and in proximity of the equipment. Larger organizations often have PM programs that help to document, prompt and report on maintenance activities. If such a system is in place it is **recommended** that the thermal spray systems maintenance requirements are incorporated.

Should such a system not exist, it is **recommended** that, at a minimum, safety-related PM requirements for the system are documented and posted at the thermal spray cell. The following is a partial list of safety-related PM items often considered unique to thermal spray (or similar) equipment.

- Vacuuming booth floor^{*2}
- Vacuuming booth walls*
- Vacuuming fixturing*
- Checking the integrity of visible radiation (UV) shields
- Checking the function of critical interlocks
- Testing/verification of pressure relief devices
- Checking and ensuring proper use of any required Personal Protective Equipment (PPE)
- Testing of emergency stops
- Leak checking and/or visual inspection of hoses / cables
- Calibration and maintenance of any gas monitoring devices

* HEPA equipment **required**.

² Powder accumulation on booth floors can be very slippery, and may create a fall hazard if not regularly removed.

7. ROBOTICS AND TORCH/PART MANIPULATION

7.1. Scope

The scope of this section is limited to the design elements necessary to mitigate hazards presented by the movement of robotic or X-Y-rotary torch mounts or part-positioning equipment within the coating booth. During normal operation, the spray booth itself is designed to isolate the operator and others from robotic arm movement and other hazards. Process control is from outside the booth itself and access door(s) are interlocked to terminate robot operation if the doors are opened during operation. This section is concerned with operation/maintenance safety during setup and maintenance functions inside the booth itself when the coating process is not running. Other elements of booth design in this document address the containment of sound/fume/gas hazards during the coating process.

7.2. Robotic Arms and Robot Systems

Defining Space in and around the Robot Arm

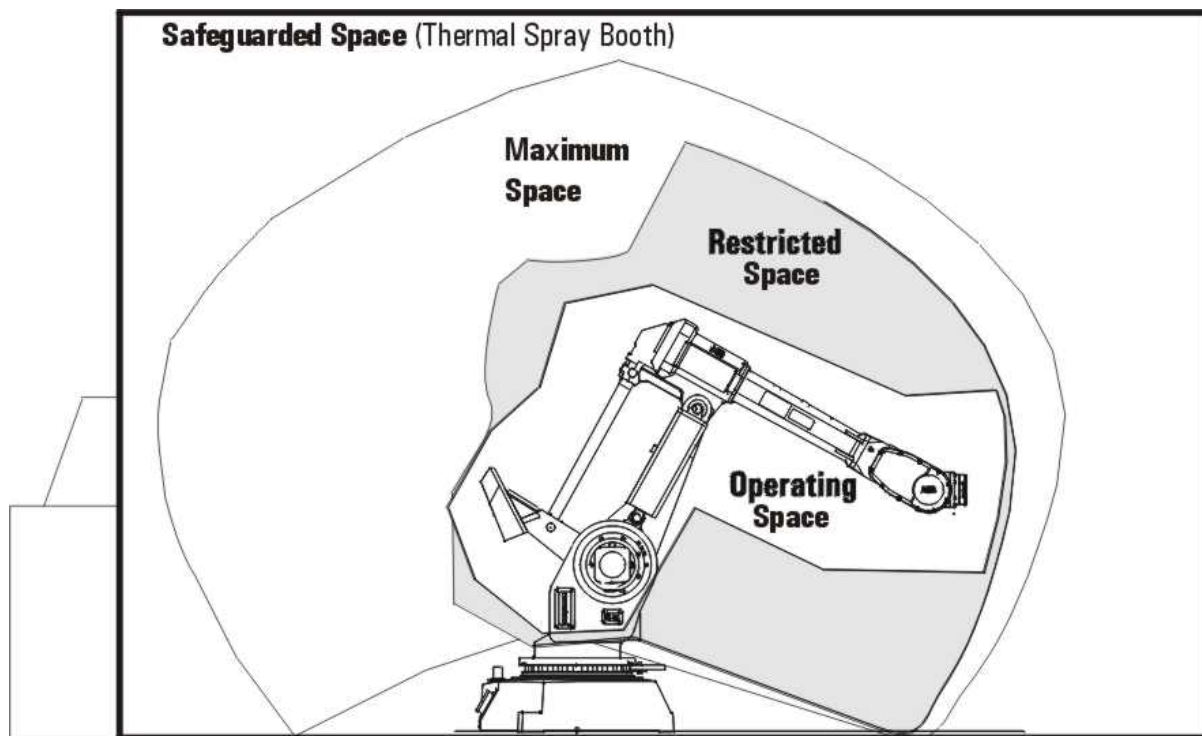


Figure 7-1. Areas of Arm Movement Defined as Specific Spaces

The ANSI/RIA R15.06 Standard defines the **Operating**, **Restricted**, **Maximum**, and **Safeguarded Space** around a robot arm. These are terms applied to a 3-dimensional envelope through which the arm can move, or a larger area where a safety hazard may result from unexpected arm movement with the potential for pinch hazard creation between the arm and other physical elements of the booth interior (walls, part positioning equipment, etc.).

The *Operating Space* is the arm's normal-operation, 3-dimensional space, as defined by its control system and its software or electrical limits while coating parts.

The *Restricted Space* defines a limited area through which the robotic arm *and all tooling or process equipment mounted on the arm* can move, before it encounters mechanical movement restricting stops, barriers, limits of travel, etc. if something goes wrong with the control system.

The *Maximum Space* defines the maximum area through which the robotic arm *and all tooling or process equipment mounted on the arm* can move *without* restricting stops, barriers, limits of travel, etc.

Safeguarded Space is the volume of space defined by perimeter Safeguarding devices – which in the case of a thermal spray booth, is the space within the booth itself, if it is closed and interlocked while the process is operated from outside the booth. All the previously defined spaces are contained within the Safeguarded Space.

The Restricted Space is of greater significance for safety design because it represents the limits of possible robotic arm travel in all directions before the arm encounters mechanical stops or barriers. This space is considered hazardous while teaching or operating the robotic arm for setup or maintenance. The Restricted Space is, by definition, larger than the Operating Space and **requires** definition by examining the range of possible arm movement and its proximity to all booth walls and fixtures at every point over its articulation range.

It is **recommended** that the area of the Restricted Space be conspicuously identified by marking/painting a prominent color to define this critical area.

The design of a robot system **requires** anticipation of all potential pinch points and their elimination wherever possible. Any hazards identified must be made conspicuous by one or more of the following devices:

- Mechanical Movement Restricting Stops,
- Warning/Interlock Devices,
- Awareness Barriers,
- Warning Signs,
- Written Procedures,
- A combination of the above.

These remedies should be employed in the priority listed, with elimination of pinch points by mechanical means given the highest priority.

7.3. Installation Configuration and Restricted Space

The configuration used for a robot installation affects the method for defining the Restricted Space of robotic arm movement. Below are descriptions of three types of installations that utilize robot arms: Fixed, Portable, and Track-mounted.

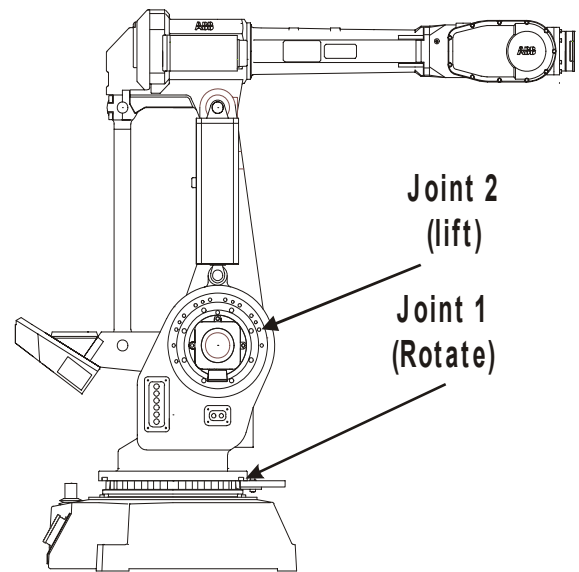


Figure 7-2. Robot Joint Identification

Fixed Robot Installations **require** mechanical stop, motion-limiting restrictions that physically attach to the major rotation and lift joints of the robot arm. These are typically identified as Joints 1 and 2 (see Figure 7-2). Stop kits for this purpose are normally available from the robot arm manufacturer. These will restrict pinch points between the arm and booth walls or other fixtures/structures. In addition, signs and labels must be applied to all areas that cannot be restricted by mechanical means. Finally, the limits of the Restricted Space must be clearly marked or painted on the floor of the work area in such a manner that the scope of robotic arm movement is immediately obvious to an uninitiated individual.

Portable Robot Installations **require** mounting in predefined and repeatable locations so that they can be treated as fixed installations where all of the above precautions can be accommodated. If these locations are not in a booth considered to be a Safeguarded Space, suitable “Awareness Barriers” and interlocks must be employed to create a Safeguarded Space and protect plant personnel.

Track-mounted Robot Installations. In large booths where the robot arm is moved along a track, a careful analysis of hazards is necessary and hard stops are **recommended** to limit the motion of the robot to the Restricted Space. Awareness Barriers are strongly **recommended** as well. These are devices that may be used to make it difficult to enter a restricted area. They may not prevent entrance; but like a knee-high plastic fence, they call attention to the fact that entering the protected area may present danger.

7.4. Teach Mode

When the robot is to be operated in a *Teach Mode*, for either teaching or verification (playback) of motion programs, this attended operation requires access to an interlocked booth which would normally prevent access to the Safeguarded Space of the robot. In some cases, the Teaching function may require the operator to actually be in the Restricted/Operating Space.

Operation of a robot in Teach mode typically involves only selection of that operating mode at the robot control console and depressing a Teach Pendant enabling device. It is **recommended** that the control system require the operator’s presence inside the booth, but *outside the Restricted Space* in case any sudden unexpected movement of the Robot occurs. This can be accomplished by using a presence-sensing switch in a safe location inside the booth near the robot, but outside the Restricted Space. The position for this switch is selected to allow visual observation of Restricted Space prior to enabling the robot in Teach mode.

Three-position enabling devices permit operators to stop machine motion by simply releasing, or tightening, a grip on a safety switch. These have the advantage of stopping motion when the device is either released or tightly squeezed in a panic situation, or even if the operator is trapped or unconscious. Speed-limited teach modes that allow only careful deliberate motion are **recommended** during an operation where a mishap, or involuntary action, can occur.

When using the enabling device in combination with the presence-sensing switch the following safeguards can be implemented:

- If a *speed-limited* Teach Mode is selected, the operator may be allowed into the Restricted Space after the Robot is enabled.
- If *full-speed capability* Teach Mode is utilized, circuit design must require the operator to remain outside the Restricted Space in order to enable the robot, and additional clearance around the Restricted Space is **required** by ANSI/RIA R15.06 Standard.
- Appropriate Warning Signs and teach-enabled strobe lamps to warn others of a teach operation in progress.

7.5. Other (Non-Robotic) Torch/Part Manipulation Systems

Thermal spray coating booths use a wide variety of torch and part positioning equipment that is capable of movement in X, Y, Z or rotary axes. These manipulators may not be called Robots, but have similar safety concerns. The manipulation equipment may be under software or hardware control and is frequently operated from inside the booth to effect setup of the process. The movement of this equipment with an operator in close proximity presents the possibility of pinch hazards between the equipment and other physical elements of the booth interior (walls, part positioning equipment, etc.).

It is **recommended** that the design of any manipulation system include the study of all movement hazards that may be created, by examining the range of equipment movement and its proximity to all booth walls and fixtures at every point in its range.

A Risk Assessment is **recommended** for all installations where torch and part-positioning equipment motion during setup or maintenance may present a pinch or other hazard to operating or maintenance personnel. A Risk Assessment **requires** anticipation of potential hazards and elimination where possible. Any hazards identified must be made conspicuous by one or more of the following devices:

- Mechanical movement restricting stops or limits,
- Warning/Interlock devices,
- Awareness barriers,
- Warning signs,
- Written procedures,
- A combination of the above.

7.6. ANSI Risk Assessment

ANSI/RIA standards **require** that safeguards be designed into a system to protect operators and maintenance personnel. These safeguards may include presence-sensing devices, barriers, awareness signals, procedures, and training. The means selected for safeguarding personnel is **required** to be based on a formal Risk Assessment that meets ANSI/RIA standards and must consider the following:

- The size capacity and speed of the robot/manipulator axes arm.
- The process.
- The tasks required for continuous operation.
- The hazards associated with each task.
- Anticipated failure modes.
- The probability of occurrence and probable severity.
- The level of expertise of exposed personnel and their frequency of exposure.

For Risk Assessment procedures, consult ANSI/RIA R15.06 Standard: Safety Requirements for Industrial Robots and Robot systems, or TSS SG002-02 Safety Guidelines for Performing Risk Assessments.

8. VENTILATION AND FILTRATION

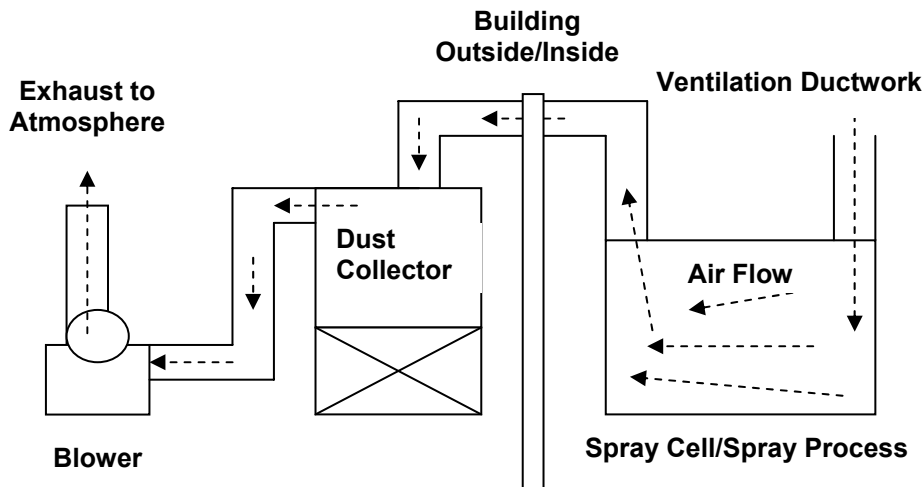


Figure 8-1 Typical Equipment Layout.

8.1. Scope

This section covers the basic elements of booth ventilation and filtration to be considered when designing, installing, and maintaining an exhaust system for use in thermal spray booth applications. It is intended to give the reader an overall background into the technical and regulatory requirements as well as other recommendations and considerations important to designing a spray booth.

It is common to have considerable ongoing legislative activity concerning ventilation systems and the release of harmful materials into the atmosphere. Details of any specific pending regulatory requirements are beyond the scope of this document and are typically focused on specific materials used in the thermal spray process. It is **required** that ventilation/filtration systems comply with local regulations and **consider** pending and future regulatory requirements. Consult a ventilation professional expert in requirements for your area to ensure compliance.

8.2. Reasons for Ventilation and Filtration

The use of air flow in the thermal spray process is **required** to meet world-wide operator safety and environmental regulations. The reasons for having an exhaust system are as follows:

- Provide adequate airflow through the booth to prevent the buildup of combustible or explosive gases in the enclosed area in order to allow safe operation of the thermal spray process.
- Proper air flow removes gases, fumes, reaction by-products (metal compounds and gases), and dust particles from the air inside the spray booth, and prevents inhalation by personnel working in the area, and filtration prevents contamination of the environment.
- Thermal spray processes use gases to convey the coating materials to the flame, plasma or arc. During the coating process, the effluents from the coating process that are not consumed by the process, or deposited on the part, must be removed from the spray environment to protect the equipment and prevent operator exposure to hazards.
- Thermal spray processes produce heat, which if not removed will slowly elevate the booth temperature to unsafe levels.
- Improper ventilation can have detrimental effects on coating quality.

8.3. Types of Dust Collection Equipment

Of the many types of dust collection components available, the combination of equipment utilized must be based upon the specific thermal spray process, application, applicable codes, and installation requirements.

Water wash units used primarily before the 1980s, are a wet method of dust collection. The dirty effluent gases and fumes from the process are passed through a water curtain or water cyclone to remove particulates. In most locations around the world these units no longer meet environmental requirements as this type of equipment is not very efficient at removing particles, and proper disposal of the wet waste has become increasingly cost prohibitive.

Dry dust collection units used primarily since the 1980s, use highly efficient dry filters to capture the particulates. Exhaust air is forced through the filter media in these units and can remove much higher percentages of the particles. Current designs use replaceable cartridges (typically 99% efficient), or bags that achieve efficiencies in excess of 95% in order to meet EPA, state, and local regulations on industrial plant emissions. This type of unit is generally **recommended** for thermal spray installations.

High Efficiency Particulate Air (HEPA) filters are used as secondary filters in addition to primary filtration. These filters enhance the cleaning efficiency of dry systems. These units consist of a housing that holds layered cubes of filter media. Air is passed through the media to capture 99.97% of fine particles as small as 0.3 microns. These units must be used in conjunction with regular dust collectors as they are not designed to handle substantial amounts of particulate matter.

Cyclones, used in addition to dry dust collection, enhance the cleaning efficiency of dry systems by enabling the capture of larger amounts of dust entrained in the air stream before they reach the primary dust collector. They help prevent damage to the fragile dust collection cartridges and/or bags by trapping large and/or hot particles that could otherwise damage these filters. A cyclone works by swirling the dirty air in a downward direction around the outside of a spiral path then pulling the air straight up the middle. Large particles are forced down into a collection drum, unable to travel upward with the air. The overall efficiency of dust removal is rather low but these devices excel at removing large amounts of particulates.

Recirculation Systems for the ventilation system are being used in some installations. These systems circulate a portion of the exhaust air in the interest of minimizing heat loss in cold climates and reducing energy consumption (and the associated CO₂ emissions). These systems **require** careful design and close monitoring of their operation as the re-circulated gases will contain by-products of the thermal spray process (such as ozone, carbon monoxide, and nitrous oxide) as well as dust and fumes from the powder being used, and therefore are generally **not recommended**.

8.4. Design Considerations

Spray Process

When considering the design of a complete exhaust system for a thermal spray process, attention must be paid to the specific process(s) and output of the process(s) intended for the spray operation. In particular the following must be **considered** with the design of an exhaust system.

Gases – The gases used and produced vary between thermal spray processes. A plasma gun uses mostly inert gases, but can use hydrogen, which is an explosive gas. Combustion processes, including HVOF, use explosive or combustible gases and oxygen. Other gases that may be used include air and carbon dioxide. The prevention of the buildup of combustible gases in an enclosed spray booth is **required** in order to allow safe operation of the thermal spray process. Under no circumstances can the buildup of combustible products be allowed in any spray booth as the thermal spray process itself is a guaranteed source of ignition. The total flow of gas should

be considered in the calculations used to determine the necessary ventilation air flow. The types of gases as well as the safe dilution of all leaks or other gas release contingencies (including full flow) must be considered in the design of safe ventilation/filtration systems.

The types and forms of materials – Materials used in the spray process also vary. As the hazardous properties of materials can vary greatly, the proper selection of components and air flow requirements are important. It is **recommended** that the actions taken in the design, with regard to the materials used, be documented. There are many regulations regarding emissions that may **require** this documentation. The following information is needed at a minimum:

- Types of materials to be sprayed and their general classification with regard to toxicity and flammability. This information can be readily obtained from each material's MSDS sheet.
- The allowable exposure levels (TLV, PEL, REL, etc.) must be known, to allow system design to control these levels.
- Annual consumption of each material based upon spray rates and hours of operation.
- Expected inflow of each material (overspray) into the dust collector for a given unit of operating time.
- Calculated emission of each material into the atmosphere on an annual basis given the information above and the efficiency of the dust collection system.
- Calculated air-to-media ratio in the exhaust stream along with the manufacturers **recommended** ratio for the filters.

Fumes – Most thermal spray processes produce fumes that need to be taken into consideration during the selection of components and air flow requirements. The Electric Arc process generally produces a high volume of fumes. Filters with lower air to media ratios are typically **required** in order to properly handle fumes without clogging the exhaust stream.

Heat –Thermal spray processes produce excess heat which elevates the exhaust air temperature. Process heat input is diluted by the presence of air flow. Insufficient air flow can result in dangerous exhaust air temperatures. It is **recommended** that air temperatures never be allowed to exceed the design specifications of the filter elements.

Reaction by-products –Thermal spray processes use different gases and materials that may generate various reaction by-products. Control of these materials must be **considered** in the overall design of the system. For example, water vapor can condense from the exhaust gases of a combustion process and come in contact with dust particles that have accumulated in the air handling and filtration systems. This interaction can release hydrogen gas resulting in a potentially explosive or flammable condition. Additionally exothermic reactions can occur resulting in sufficient heat build-up to start a metal fire. Also, metal powders can form complex metallic compounds (such as hexavalent chromium or nickel carbonyl) as a result of their exposure to the high temperature of the spray process. The compounds can have risks and exposure limits which are different than the starting material. It is **required** to follow the recommendations of thermal spray equipment/consumables suppliers to alleviate potential hazards by incorporating booth design considerations to minimize the effects/hazards of these by-products.

Exhaust Equipment and Facility Layout

The design of the overall exhaust system is dictated by the physical layout and size of the spray booth enclosure and the exhaust equipment locations. The following steps are **recommended**:

- The dry dust collection components and exhaust blower should be located outside the building, preferably near the spray booth. Depending on the process and materials to be sprayed, **consideration** should be given to incorporating explosion relief panels in the filter housing and using flame-resistant filter media. In situations where hazard levels are controlled and understood, inside locations or collectors within the booth itself may be **considered**. Locating dust collector and blowers inside of occupied buildings may require additional measures for hazard control and may not be permitted by local codes. At the very least, locating dust collection systems inside a building will involve additional costs for fire/explosion prevention measures.
- Larger spray booths typically **require** a higher air velocity to capture and carry particles to the collection system. Spray booths should be sized just large enough to allow for safe processing, where practicable, including spray equipment clearances, without additional space.

Air Flow Design Considerations

Proper air flow in a spray booth is a necessary engineering control used to reduce operator exposure to thermal spray dust particles, fumes, gases, and volatile substances. This control, however, does not eliminate the need for a suitable respiratory protection program for each thermal spray facility, in order to determine the necessary Personal Protective Equipment (PPE) required to protect the operator during all aspects of job performance. Such a program is typically the responsibility of the employer.

The airflow for a thermal spray process is dependant upon several factors and must provide adequate ventilation of the spray booth. The factors that follow include considerations for the coating quality, personnel safety, and overall cleanliness.

1. **Air Flow Velocity** – To remove airborne particles from a thermal spray booth, typical airflow velocities in the range of 75 to 200 feet per minute (23 to 61 m/min.) are **recommended**. In larger booths it is more difficult to obtain the *higher* velocities in this range, and the velocities at the *lower* end of the range may be insufficient to capture and remove all particles. However, the higher the velocity achieved – the closer to the upper end of the range – the cleaner the booth will remain.
 - a. For spray booths where robotic or automated equipment is performing the spray operation, it is **recommended** that air velocities within this range be achieved for the purpose of keeping the spray booth clean.
 - b. For spray booths equipped with a spray hood and where all activities associated with the spraying of parts occur near a hood positioned at the source of the process effluents, capture velocities at the face of the hood should be near the upper end of the recommended range.
 - c. For spray boxes, the typically smaller internal volumes will allow capture velocities greater than the upper end of the range.
 - d. Air velocities in the vicinity of 300 feet per minute (91 m/min.) may adversely affect the thermal spray process, especially in cases where the spraying is done at right angles to the air stream.
2. **Heat Dissipation** – The total air flow to a spray booth is **required** to be sufficient to prevent exhaust air temperatures from exceeding the design temperature specification of the filter media and ductwork.
3. **Total Air Flow** – The total **recommended** air flow for the spray booth should provide for a minimum of 5 air changes of the entire spray booth volume per minute. For typical large booths, the rate may vary from 1.5 to 5 air changes per minute due to lower practicable flow rates because of the larger volume of these facilities.

In any configuration, the greater the number of air changes per minute, the better. For adequate dilution of full-flow process gases, necessary to prevent excess accumulation during leaks or other malfunctions, the ventilation system needs to be designed to provide sufficient dilution of process gas leaks to levels safe enough to prevent the accumulation of explosive or hazardous atmospheres.

4. **Negative Booth Pressure** –The spray booth air intake and exhaust should be balanced at the design air flow to provide a negative pressure relationship between booth and the rest of the building with the exhaust system operating and all spray booth doors closed. This is to ensure that any leaks in the booth structure will allow plant air into the booth, and will not allow gas, fume, or dust leaks into the plant environment. If ventilation system intake air is from *inside* the building, this negative pressure should be 0.3 to 0.5 Inches of water (0.75 to 1.24 mBar) of static pressure drop between the spray booth and the plant atmosphere. Pressure differential values lower than these may result in interaction between the changes in building and spray booth pressure due seasonal changes or air makeup systems. If the ventilation system intake air is from *outside* the building, the negative pressure range may be from 0.1 to 0.5 Inches of water (0.25 to 1.24 mBar)

Pressure drops higher than 0.5 Inches of water (1.24 mBar) will result in negative pressures sufficient to exceed OSHA standard for ingress/egress using the spray booth doors. The following exceptions apply:

- a. Spray booths that need to be accessed only for maintenance purposes.
 - b. Spray booths and chambers with door actuators that supply mechanical assistance for operation.
5. **Dual-Speed Exhaust systems** – Dual speed exhaust fans are **recommended** to allow the system to maintain a low-level ventilation mode at all times when the booth door is open and when the booth may be occupied for maintenance or setup, and revert to a high-level or normal operation when the booth is closed for process operation. This type of system improves air quality and sweeps away any small quantities of residual gas and dust particles that might remain in or be leaking into the booth during maintenance or setup operations when the booth is occupied
 6. **Sound Control** – It is **recommended** that air intakes to the spray booth located inside the building provide sound control in the form of acoustic insulation, duct silencers, etc. to attenuate noise emitted by the process within the spray booth.
 7. **Inlet Air Flow** – The inlet air flow for the thermal spray process can be from inside the facility in which a booth is installed, or from outside the building.
 - a. When the inlet flow is from *inside* the building, air exhausted from the building must be considered for its overall effect on the building ventilation system. This can be accomplished in several ways and varies depending on local codes and heating and cooling energy conservation concerns. Check with a professional industrial ventilation expert for specific local requirements and recommendations.
 - b. In installations where air is to be fed to the air intake of the spray booth directly from *outside* the building, consideration must be given to conditioning (heating or cooling) the air to the interior of the booth, as may be required.
 8. **Airflow Distribution** – The airflow within the spray booth should be uniformly distributed through careful placement of the air intake and exhaust plenums. The smoothest possible flow of air (Laminar flow) is very beneficial to the effective removal of dust from the process area and carrying it into the ducts leading to the filters. Laminar flow can best be achieved using an inlet plenum with many small evenly-distributed inlet air openings– fewer larger opening create turbulent flow. Smooth air flow through the booth minimizes dead areas that allow accumulation of effluent. Turbulent flow can create eddies and low pressure areas that cause dust to be trapped or dropped from the air stream. Booth obstacles such as tooling, parts, and fixtures detract from smooth air flow. Exhaust plenum placement on opposite ends of the spray booth from

the air intake is **recommended** as part of an overall design to enhance smooth flow. Positioning of the exhaust plenum is typically on the wall or floor just beyond the process.

The layout of the spray booth interior should take into consideration the effect that objects in the booth may have on air movement within the booth. The following layout guidelines are **recommended**:

- a. Process control equipment that must be placed inside the spray booth such as powder feeders, flow meters, etc, should be placed in the spray booth near the air inlet and away from the actual spray process. Process equipment requiring maintenance operations, such as adding powder, etc. is **recommended** to be positioned in the ventilation stream so as to minimize operator exposure to additional dust or fume hazards during the maintenance operation.
- b. Robots, gun manipulators, and spray operators should be placed near the center of the spray booth facing the exhaust plenum/spray hood with the part to be sprayed between the exhaust plenum and the robot/manipulator.
- c. The workpiece to be sprayed and any workpiece manipulation equipment such as turntables or spindles should be placed in front of the exhaust plenum.
- d. A combination of floor/cross-flow ventilation is sometimes used to minimize accumulation of heavier particles on the floor nearest the thermal spray process. In this type of system, additional ventilation ducting is added under the floor (via grate or other means) with capture exhaust inlets near the coating point itself to prevent accumulation at that location.

Ventilation Ductwork

Due to the nature of entrained particulates in the exhaust air stream, consideration must be given to the design of the overall ductwork. For specific details on duct layout and design consult SMACNA (Sheet Metal and Air Conditioning Contractors National Association). It is highly **recommended** that a competent local contractor be used to fabricate and install the ductwork in compliance with federal, state and local codes. The following are a few safety-related concerns:

Duct Velocity – The **recommended** air velocity inside the ductwork between the spray booth and the dust collector should be a minimum of 3,500 feet per minute (fpm) (17.78 m/s) to a maximum of 4,000 fpm (20.32 m/s). A lower air velocity will allow particulates to settle out of the air stream and build up in the ductwork leading to potential fire hazards, placing additional weight on ducting, and possibly blocking airflow. Inlets to dust collection equipment will often need lower velocities to prevent possible erosion of filter media and to disperse the air flow across the filters.

Duct Bends –The ventilation system exhaust air stream carries a large amount of momentum as a result of the relatively high velocity and entrained particulate. Give **consideration** to limiting the number of bends the air must make between the spray booth and dust collector. Bends increase pressure drops, and can create locations where material can build up.

Back-draft Damper – At the point where the ductwork leaves the building, a back-draft damper installed into the ductwork is **recommended**. The back-draft damper serves to prevent the reverse flow of air from outside the building back into the spray booth when the exhaust system is off, and also serves to prevent smoke from any potential fire in the dust collector from backfilling into the building.

Duct Class/Shape – Ductwork can be either rectangular or circular in cross-section depending upon contractor or local supply preferences/availability. Duct sections are **recommended** to be of a heavy-duty gauge and construction to handle the pressure and powder loadings presented by the booth ventilation requirements and in compliance with any local codes. Ventilation ductwork used primarily for air conditioning systems is not normally considered adequate for this task.

Local Codes – Many state and local codes have restrictions on how the air can be exhausted. Of concern is the need to prevent accidental intake back into the building or other contamination factors. Even though the air is clean of particulates it will still contain spent process gases, or volatile by-products, which in many cases can be harmful.

Intrusion – Protection against animal and weather intrusion into the ductwork is **required** at the point where the ductwork ends.

8.5. Operation/Maintenance Considerations

Consideration must be given to the safe operation and maintenance of the overall exhaust system, during the selection of dust collection components. Specifically, the following concerns need to be addressed:

Operation Concerns

Cleaning – During operation, all of the types of collection units mentioned **require** regular maintenance to remove the buildup of collected material. The frequency of maintenance depends upon actual usage; the methods vary depending upon the system. Dry collection and cyclones are generally emptied directly into 55 gallon (208 L) drums or other suitable containers. HEPA secondary filters capture dust particles within their filter layers and typically cannot be cleaned. They must be properly discarded when full. Most waste from the dust collection system is considered HAZARDOUS WASTE and must be disposed of in accordance with all applicable regulations.

Fire and Explosion Prevention – Due to the hazardous nature of some of the materials and gases used, attention must be paid to reducing the risk of fire and/or explosion within the dust collector and ductwork. As each situation varies greatly in the potential risks and applicable codes, it is advisable that an expert be consulted. The use of explosion venting, thermal cutouts, back-draft dampers, and associated fire/explosion prevention devices must be considered for each application, and in some cases, are **required** by law.

Where there exists a general concern for combustibility of loaded filter media, the following steps should be **considered** as minimum preventative measures:

- **Control main ignition source** - Often the ignition source of main concern is hot particles from the process, parts, tooling or masking. Duct work of sufficient length, duct inlet screens, etc. can be beneficial in preventing hot particles from reaching filters and collected waste. Tooling and masking should be made of non-combustible materials.
- **Detect the fire** - A temperature sensor downstream from the filter media can be considered as an inexpensive method for detecting a filter fire.
- **Warn and control** - Upon detection a warning should sounded. Additionally, in most situations, fans should be turned off and dampers on both sides of the filter housing should be closed. This serves to limit air to the fire and slow combustion.

Sprinkler Systems - Although systems exist that use different materials such as special chemicals, foams and gases to suppress fires, in many cases the use of water sprinkler systems is considered due to wide usage of such systems in general industrial and residential applications. Water is, in most situations, not a good solution for various reasons:

- Leaking or inadvertently activated sprinkler systems can permanently damage filter media.
- Water can cause potentially dangerous reactions with some materials and metal dusts found in thermal spray filter systems (spray material history dependant).
- Water can turn dry hazardous waste into liquid hazardous waste leading to unplanned environmental releases and cleanup issues.

Sprinkler or spray materials other than water require confirmation of compatibility with the media and waste materials found in the filter system. In many cases the supplier of the thermal spray equipment or the filtration system can provide recommendations regarding safe and cost effective methods to control fire/explosion hazards.

Vent Gas – Prior to turning on gases, powering up equipment, or entering the booth, it is **recommended** that the exhaust system be turned on and allowed to run for a few minutes to purge the spray booth and exhaust any potential buildup of hazardous gases should a gas leak occur.

Smoking – It should be a local **requirement** that no smoking be allowed in a spray booth. The likelihood of a smoldering particle of smoking media making it to the dust collector filters is very high and has been known to start fires.

Vent System Maintenance Concerns

Exhaust equipment should be checked for proper operation at regular intervals depending on the characteristics of the process/facility. An inspection schedule is **recommended** for regular examination of ventilation ductwork, and exhaust system components in accordance with the manufacturer's instructions. The following items should be checked as a minimum:

- Level of material collected for emptying.
- Pressure drop across filters.
- Traps and screens in hoods and plenums for material buildup.

8.6. Example Case

This example case of a robotic spray booth depicts a typical situation that serves as a model of the layout and functionality **recommended**. Always check local codes for additional requirements that may not be shown in the examples.

Typical Robotic Spray Cell

The typical robotic spray booth depicted in Figure 8-2 shows the arrangement of equipment and airflow for the system. It should not be considered a complete representation as there are many details in the design and fabrication of the components that cannot be shown. Note the following features:

1. The flow of air through the spray booth from the back to the front, supplying a clean wash of air across the robot and turntable.
2. The relatively (not to scale) small size of the exhaust duct from the spray booth to the dust collector to keep air velocity high enough to prevent particulates from settling out in the ductwork.
3. The robot placed near the center of the spray booth facing the exhaust plenum/spray hood with the part to be sprayed between the exhaust plenum and the robot.
4. The workpiece to be sprayed and turntables placed in front of the exhaust plenum.
5. At the point where the ductwork leaves the building, a back-draft damper is installed into the ductwork to prevent the reverse flow of air from outside the building back into the spray booth when the exhaust system is off.
6. A HEPA filter is not shown. **If required** it would be normally placed after the blower.

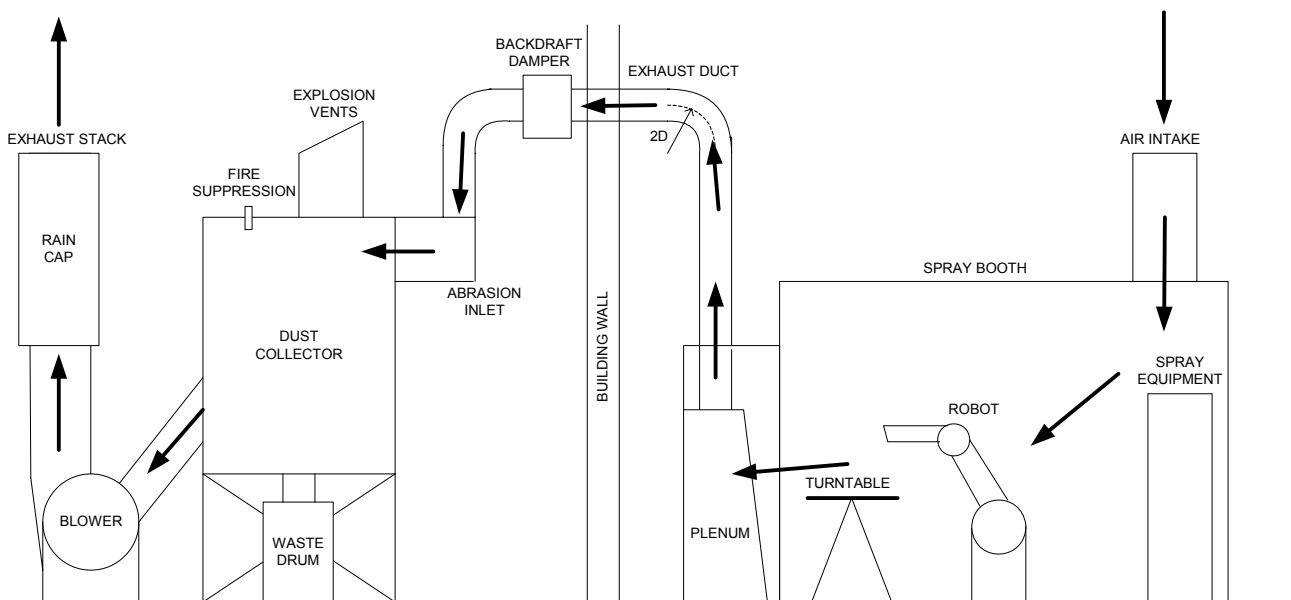


Figure 8-2. Typical Robotic Spray Booth Configuration

9. PIPING GUIDELINES

9.1. Scope

The section on gas handling and piping is designed to provide information to increase safety awareness and use of safety practices with regard to gas and liquid piping to and around typical thermal spray installations.

The focus of this section is the process piping leading to the thermal spray cell and to specific thermal spray equipment within the cell. A typical thermal spray installation will involve Branch process piping leading to the thermal spray booth, usually terminating in the Station Outlet valves at the booth. A combination of piping and hoses is typically utilized from these station outlet valves to various devices around the booth. This section is not intended to apply to plumbing within manufacturer supplied consoles or equipment nor will it address bulk gas supplies and main line process piping within the facility.

9.2. Typical Gases/Fluids

The following is a list of common gases and fluids used in typical thermal spray installations.

- Compressed air
- Carbon Dioxide
- Argon
- Nitrogen
- Helium
- Hydrogen
- Acetylene
- Propane
- Propylene
- Methane
- Natural gas
- Oxygen
- Water
- Kerosene
- Carbon Dioxide
- Custom mixes (MAPP, Crylene, etc.)

9.3. Supply Planning

For most thermal spray installations, gas and/or fuel supplies will be piped into the building from either a permanent or temporary bulk source installation located external to the building. Flow demands will dictate the capacity of the bulk gas supply, which is typically installed in a secure location outside the building to meet the requirements of various building fire codes and regulations.

For some installations, however, flow needs can be handled by a single local supply tank or cylinder located nearer to the thermal spray booth. In some cases it is acceptable, and sometimes preferable from a safety perspective, to store such a container within the building. Local codes vary considerably on this issue and should be consulted if considering internal storage and supply of any gas. In some instances, regulations state the maximum size of a cylinder or container that may be housed or stored inside. This depends on the type of building or the type of storage. The nature of the installation, either temporary or permanent, can also be a factor in determining which regulations apply. The gas supplier can be an excellent resource regarding proper configurations and locally acceptable practices.

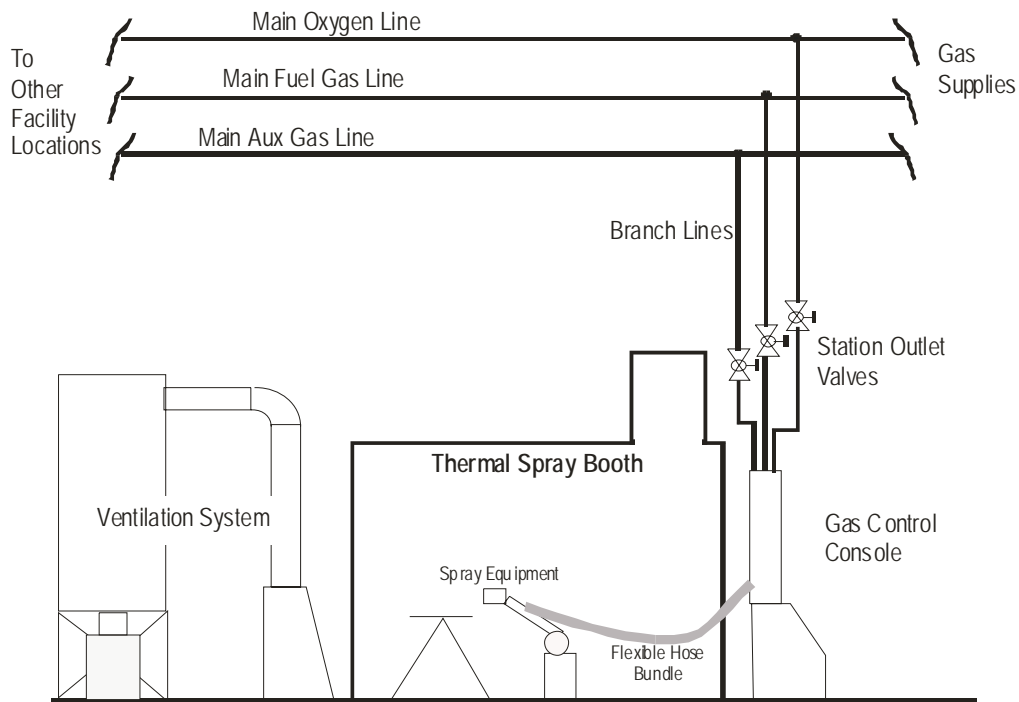


Figure 9-1. Typical Thermal Spray Booth - Gases will vary with the process.

9.4. Piping Materials

For typical gases and fluids used in thermal spray applications, branch piping is normally implemented using black iron, carbon steel, or stainless steel hard piping with welded or threaded joints. The individual physical or chemical characteristics of each gas or fluid **require** that specific piping materials are employed to ensure compatibility and safety. In addition, local standards and governmental regulations are often specific regarding materials or types of piping utilized for specific gases and fluids.

The gas supplier, building contractor, or thermal spray equipment supplier can all be valuable resources in determining proper plumbing materials and types. The following list suggests typically accepted materials by the gases and fluids carried --*None of these may be considered as complete requirements for gas/fluid piping materials:*

Argon, nitrogen, and helium are typically piped using black iron, carbon steel, or stainless steel with welded or threaded fittings. An additional preferred material is drawn copper piping which is permitted because of the inert nature of these gases.

Hydrogen is typically piped in black iron, carbon steel, or stainless steel with welded or threaded fittings. *Low temperature or soft materials such as copper or brass are not permitted due to susceptibility to heat or abrasion damage and the flammable nature of this gas.*

Acetylene piping typically employs black iron, carbon steel, or stainless steel pipe with welded or threaded fittings. Due to the chemically unstable nature of acetylene it has the ability to support combustion and powerful detonations without the presence of an oxidizer. For this reason, specific and stringent construction codes **require** that the piping materials used for acetylene provide sufficient strength to contain such incidents without damage. Construction codes differ throughout the world. Contact the local gas supplier for recommendations. *Copper or alloys containing copper must not, under any circumstances, be used for acetylene supply or venting applications. Acetylene and copper chemically react to form unstable compounds which themselves can be hazardous.*

Propane, propylene and natural gas are typically piped in black iron, carbon steel, or stainless steel with welded or threaded fittings. Propane and propylene are typically stored in liquid form at room temperature under moderate pressure. The fuel is vaporized to gaseous form prior to distribution through building piping. Fuels in liquid form, due to their greater density, can present an increased fire hazard compared to those in gaseous form. Leak containment is also a concern with liquid fuels. For these reasons fuel gases stored in liquid form are subject to different regulations than those applicable to fuels stored in gaseous form.

Oxygen is, by itself, not a fuel gas and is not combustible, but it does vigorously accelerate the combustion of other materials and, as such, can present a significant hazard. This characteristic becomes more serious at higher pressures and flow rates. For this reason it is **required** that oxygen piping be constructed of specific materials known to be compatible with the pressures and flows in the system. Typically, thermal spray equipment that utilizes oxygen operates at pressures under 300 PSI (20.7 Bar). For these installations, black iron or stainless steel piping can be used. Copper piping can also be utilized.

All devices used in oxygen plumbing **require** special cleaning to ensure oxygen compatibility. For the reason, they must be labeled by the manufacturer "Cleaned for Oxygen Service."

Compressed air is typically piped in black iron, carbon steel, or stainless steel with welded or threaded fittings. The use of copper or various types of plastic or PVC pipe may be **considered** where careful attention is given to specific pipe pressure ratings. Local codes often dictate specifically what can be utilized in compressed air service.

Water from a City or Closed-Loop cooling supply is typically piped in black iron, carbon steel, or stainless steel with welded or threaded fittings. The use of copper or various types of plastic or PVC pipe may be **considered** where careful attention is given to specific pipe pressure ratings. Plastic pipe ratings must receive specific considerations for maximum water temperatures. Local codes often dictate specifically what can be utilized in water service.

De-ionized Water. Specific cooling requirements often dictate the use of de-ionized water. Plastic or PVC pipe is often preferred for these applications. Manufacturer's manuals and local installation codes should be consulted.

Kerosene is the only common fuel utilized in thermal spray applications that is piped to process equipment and utilized in its liquid form. For thermal spray devices, kerosene is normally piped in small diameter steel, stainless steel, or copper tubing.

Indoor storage of quantities of kerosene is typically closely regulated and leak containment is a concern for liquid fuels. For these reasons, kerosene is subject to different regulations than those applicable to gases. Consult local building codes for proper application.

Carbon dioxide is occasionally used for part cooling in the thermal spray industry. For these applications liquid CO₂ is often plumbed to the process. The **recommended** material for piping liquid CO₂ is copper. The use of iron and steel piping and components is often prohibited and should always be carefully reviewed due to the effects of low-temperature embrittlement. Certain types of stainless-steel and carbon-steel alloys are acceptable for liquid CO₂ applications. The piping for liquid CO₂ and other cryogenic liquids **require** appropriate pressure relief devices on every pipe section between components that might be capable of trapping liquid. Warming, expanding, liquid entrapped between two closed devices, if not released, will cause extreme pressure rises and may cause pipe/component rupture and potentially serious damage.

Custom mixes (MAPP, Crylene, etc.) are occasionally used in thermal spray processes. Consult the gas supplier for the recommended materials for these gases.

9.5. Piping Design

Piping material selection **requires** all piping materials used in thermal spray applications be compatible with the chemical and physical characteristics, as well as the temperature, flow, and pressure requirements of the gas/fluid to be conveyed.

- Determine the proper piping material specification for the gas to be piped from ANSI, CGA, or similar other applicable published piping standards/safety practices.
- The manufacturer's literature for the specific thermal spray equipment being installed is the recommended source for determining the pressure and flow requirements for the piping of each gas or liquid to be piped.
- The Design Pressure (Maximum Allowable Working Pressure) of a gas piping system is typically **required** to be greater than the system Operating Pressure by a minimum percentage (15% is often specified). This requirement depends on the flow rate and operating pressure requirements of the gas being conveyed. See published gas piping standards to ensure design, Operating and Test pressure relationships meet the requirements for each gas piping system.
- Flexible hoses may be used for connections to process equipment downstream of the station outlet valve and related components. When used, flexible hoses **require** a manufacturer's rating for use with the specific gas/liquid to be carried. It is **recommended** that such hoses be color coded per local conventions.

9.6. Piping Components

A *Station Outlet* valve is **recommended** at the end of branch lines supplying each individual thermal spray cell. These should be conveniently located and clearly identified so as to provide emergency shut-off capability and a place for support of lockout tag-out maintenance activities.

Pressure Relief valves are **required** to protect downstream plumbing and devices from over-pressure such as from the failure of a regulating device. When used, pressure relief devices must release at a pressure no higher than the maximum design pressure of the system. Pressure relief devices must be designed to handle the full flow of the supply piping.

Excess Flow Valves should be **considered** for flammable gas branch lines. These self-actuating valves automatically close when gas flow exceeds a predetermined rate. They deliver positive, automatic shut off when the pre-selected flow rate is exceeded, to stop gas release in the event of downstream line, hose, or instrument rupture.

Pressure relief devices are often part of pressure regulators and not individually identified. Consult the regulator manufacturer regarding such devices and their suitability to any specific task.

It is **recommended** that relief ports for pressure-relief devices used with gases other than air be piped to the building exterior. This is to prevent the creation of a dangerous atmosphere (flammable, explosive, toxic or asphyxiating).

9.7. Flammable Gas Piping Components

Check valves installed downstream of station outlet valves are **recommended** for oxygen and fuel gas lines.

Quick Disconnects, when utilized with flammable gases or liquids, or oxidizers, are **recommended** for use only within the confines of the ventilated thermal spray booth for purposes of connecting to the thermal spray gun. Quick disconnects are prone to leakage and can contribute to a fire, particularly in a non-ventilated area.

Flashback³ Arresters affixed to acetylene lines are **recommended** after the station outlet valve and at the thermal spray device or gun.

9.8. Area Classification

Typically, thermal spray equipment provides containment of flammable gases within hoses, regulators, gauges and other components outside of the thermal spray booth. Regulations, similar in the US and in Europe, **require** manufacturers to designate areas around their equipment within which it is inappropriate to mount electrical devices that might act as ignition sources (see additional information in Section 10.4). Consult the manufacturer's literature for proper spacing requirements.

9.9. Piping Fabrication

Piping Materials – All materials used during fabrication of thermal Spray piping systems are **required** to be compatible with the chemical and physical characteristics, as well as the temperature, flow, and pressure requirements of the gas/fluid to be conveyed. The external environment (temperature, physical damage potential, corrosion) must receive consideration when selecting materials.

Branch lines – These are typically are hard plumbed lines bringing supply gases and fluids from main distribution lines within the facility to a station outlet valve located at the thermal spray booth. Typically such lines are run overhead before being brought down and attached to the side of the booth. In most installations line filters and regulating components will be installed immediately after the station's shut off valves.

Piping Identification – It is **recommended** that process piping to the thermal spray cell be properly identified in order to clearly indicate the contents of each pipe. Color coding and labeling requirements differ from country to country. Consult local regulations for proper identification. As a general rule, paint is applied only over a small percentage of the pipe. Extensive paint application serves to mask leaks and prevent later identification of the piping materials used.

³ Individual thermal spray devices may require flashback arresters and/or check valves to be installed in a specific part of the system plumbing. Such usage is not limited to acetylene. These devices are often found in oxygen and fuel lines supplying thermal spray guns and gas control panels. Often such devices are installed to address specific safety and performance issues and should not be removed, modified or substituted without explicit recommendation from the manufacturer.

Piping Protection – It is **recommended** that Branch piping be routed and mounted in a manner that protects the piping from external damage or wear. Flexible hoses and lines should be routed and protected from damage and abrasion.

Grounding (bonding) Requirements – Branch piping for all flammable gases and liquids must be grounded to avoid static electricity build-up.

Cleaning – Branch and process piping cleaning is **recommended** during and after construction prior to being placed in service.

Cleaning for Oxygen Service – Piping and components designed for oxygen service **require** thorough cleaning per established practices for such service. Seemingly small quantities of foreign materials, such as oil or grease, can result in the creation of violently explosive mixtures in the presence of oxygen.

Pipe Joining and Sealing Recommendations – Pipe joining techniques should be per manufacturer's recommendation. Pipe sealing should be per standard accepted practices. Sealing compounds are **required** to be compatible with the gases to be carried.

9.10. Piping System Integrity Monitoring

Leak checking – It is **recommended** that all branch and process piping be leak checked at least every six months, or more frequently, per manufacturer's recommendations.

Gas Detectors/Oxygen Monitors – Natural and/or forced and interlocked ventilation is the preferred method for assuring safe air conditions around and in thermal spray booths. Combustible gas detectors and/or oxygen level monitors can be **considered** for use both within and outside the thermal spray booth to help warn of any unsafe conditions, but should be viewed as secondary protection and not be relied on as the primary safety measure. Detectors and monitors **require** assurance of compatibility with dust and contaminants and need regular maintenance and testing.

10. ELECTRICAL GUIDELINES

10.1. Scope

The focus of this section is the configuration of control electrics and associated equipment throughout the thermal spray cell. The section provides information intended to increase safety awareness and the use of safe practices with regard to the configuration of electrical equipment within thermal spray installations. In addition, this section will address specific recommended practices regarding critical safety related topics such as emergency stop circuits, lockout-tag out, electrics/fuel separation, etc.

The scope of this section is not intended to extend to electrical wiring and hardware within manufacturers' supplied consoles and equipment, nor will it address supply wiring normally considered part of the building facility.

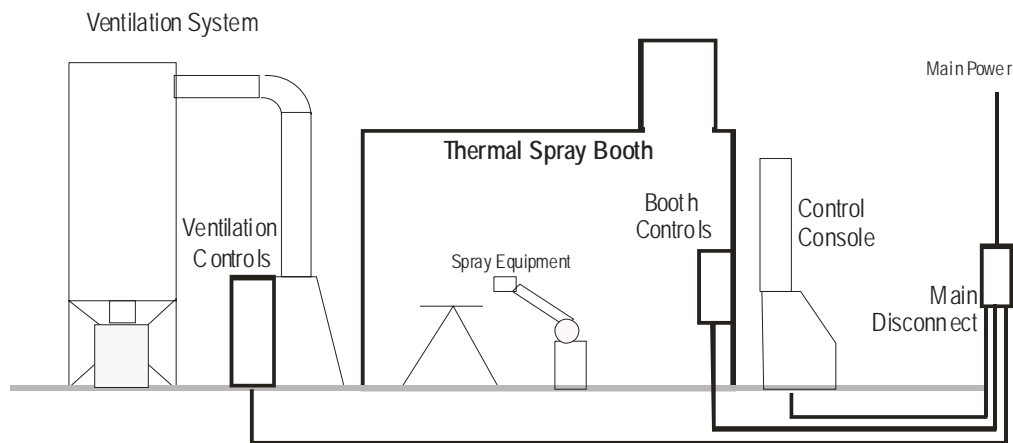


Figure 10-1. Typical Thermal Spray Booth —Typical Power Wiring

10.2. General Topics

Manufacturer's information – The manufacturer's literature for the specific thermal spray equipment being installed is the recommended source for proper voltage and current requirements for the specific installation.

Grounding/bonding requirements – Grounding of electrical cabinets, booth walls and other metallic structures must be provided. Grounding to metallic building structures or metallic plumbing is typically sufficient. Check local codes.

Adequate Access/Lighting – Electrical cabinets containing electrical equipment for the control of typical thermal spray installations typically **require** frontal clearance of 3 ft. (910 mm) for adequate safety during service activities. Consult local regulations. In addition adequate lighting of all cabinet areas is **recommended** to further enhance safety during service work.

Overload protection – Appropriate overload protection is **required** for the electrical supply in the form of either circuit breakers or fuses. Consult the National Electrical Code or local codes for appropriate configurations.

Ground Fault Interrupters (GFI) – GFI's are **recommended** for all convenience outlets mounted in, on or around the thermal spray cell. This provides extra safety protection against electric shock hazards considering the fact that most thermal spray devices use water cooling and leaks and puddling of coolant are common during maintenance.

Dust protection – Electrical components within the thermal spray booth **require** the type or design characteristics that afford protection from powder and dust.

Documentation Recommendations – Adequate documentation for each installation should be provided such as to permit and encourage safe operation, maintenance and service of the thermal spray cell and associated components.

10.3. Gas and Electrical Interlocking

Gas interlocking Requirement – Process gas flow into the thermal spray booth must be electrically interlocked through suitably rated solenoids or other automatic shutoff devices such that gases are allowed to flow only when sufficient ventilation airflow through the booth is confirmed.

Electrical Interlocks – Thermal spray installations typically present numerous hazards to operators and other personnel. It is common and accepted practice to use electrical interlocks to protect personnel from these hazards (see: 6.7 Safety Interlocks for descriptions of the hazards addressed by these electrical interlocks).

The following list represents typical **recommended** interlock applications:

- Booth door
- Robot travel
- Parts manipulating table or other motion devices
- Electrical connections
- Equipment guards
- Pressure and flow of liquids or gases
- Ventilation flow

Interlocks should be designed to discourage any attempt to defeat their function. Consult local codes for recommendations regarding interlock requirements.

Emergency Stops (E-Stop) – Emergency stop buttons are **required** at appropriate locations around the thermal spray cell. Actuating an E-Stop button will remove power (as appropriate) in an emergency, except for functions that are required for personnel safety such as the ventilation system, fire suppression, hazard alarms, etc.

Typical E-Stop functions include:

- Process Gas flow
- Ignition
- Arc Power sources
- Motion Control
- Hydraulics
- Robotics
- Control Power

E-Stop button location(s) must be selected to afford operator and maintenance people quick access in case of an emergency. E-Stop buttons are typically of the “push to energize pull to release style”. Emergency stop circuits must be designed so that when an E-stop button is reset, the system does not automatically re-energize. A separate reset or start action must be **required** to avoid unexpected restarts of the equipment after the source of an emergency stop has been corrected. In addition, for integrated systems, emergency stop buttons must be interconnected so that all E-Stop buttons in a cell perform the same emergency stop function. In some locales, the use of dual channel safety circuits is a requirement. Consult local codes for guidance.

Lock-out/Tag-out – System shutoff means are **required** to allow all energy sources to be disconnected and isolated from the thermal spray system or cell. Such shutoff devices must be equipped to accept a lockout device and associated tag to prevent accidental re-energizing of the equipment and subsequent exposure to hazards.

10.4. Area Classification

Typically thermal spray equipment provides complete containment of flammable gases within hoses, regulators, gauges and other components both outside and within the thermal spray booth. Since leaks can and do occur, regulations – similar in the US and in Europe – **require** manufacturers and/or users to designate areas around their equipment within which it is inappropriate to mount electrical devices that might act as ignition sources for flammable gases. These areas are referred to as *classified* or *zoned* depending on national/local conventions and rules. Consult the manufacturer's literature for proper spacing requirements.

Often cabinets or enclosures are utilized to protect or contain components that in turn carry or contain flammable gases. It is always wise to adequately, and preferably naturally, ventilate such enclosures to aid in the dispersion and dilution of any potential gas leaks. Typically the entire internal area of such enclosures and suitable surrounding areas external to the cabinet are considered classified or zoned areas.

Electrical cabinets, consoles and other electrical boxes are normally positioned so as to avoid combustible gas classified areas. When such devices encroach on a classified enclosure area, typically the inside of that enclosure becomes a classified area. In these cases, appropriate steps are **required** in order to de-classify the electrical enclosure. Purging and pressurization, natural and forced ventilation, and other means exist to de-classify such areas. Consult the National Electrical Code or NFPA 497 for further guidance.

In cases where the extent of hazardous (classified) areas/zones or specific spacing recommendations are not available from the manufacturer, the following **recommendations** are offered to help promote safe installations and operations.

Cabinet Ventilation – A high degree of natural or interlocked artificial ventilation to a cabinet is especially important and **required** for cabinets containing both combustible gas carrying components and electrical components. This is to prevent containment or concentration of potential leaks. Such cabinets should be designed with a high degree of natural ventilation. Expanded metal grates, extensive louvering, and open cabinet tops and bottoms are typically used to increase natural ventilation. It is a **requirement** that when forced (fan driven) ventilation is used, gas flow to a cabinet is interlocked so that flow is blocked if insufficient ventilation is sensed.

Cabinet/Component Location – Cabinets containing non-classified or non-rated electrical components that are considered ignition sources⁴, or individually-mounted ignition sources, should be separated from gas carrying components or cabinets by a minimum of 16 inches (406 mm) for typical thermal spray equipment.

Spray Booth Area Classification – It is **recommended** that electrical components are separated by 12 in. (305 mm) from flammable gas connections where practicable within the booth. Thermal spray booths are typically provided with forced ventilation systems designed primarily for the removal and filtration of effluent containing unused powder and combustion or arc by-products. Such systems typically more than adequately fully dissipate and dilute any fuel gas leakage. When such systems are interlocked (see: 10.3 Gas and Electrical Interlocking) to interrupt process gas flows in case of insufficient ventilation most areas within the booth can be considered non-classified (not requiring rated electrical components). In addition, the interiors of such booths are designed for combustion to occur during normal operation.

If sufficient separation is not possible, electrical cabinets should be protected either by:

- Using components rated for use in the specific hazardous (classified) area or zone.
- Purging and pressurization of the electrical cabinet.
- Barriers or other protection devices or schemes.

⁴ Ignition sources are typically defined as devices that, during normal operation, could ignite combustible gas concentrations. Unprotected and/or non-rated switch and relay contacts, centrifugal switches, open spark gaps, plugs and sockets that are connected and disconnected during normal operation, devices with hot surfaces with the possibility of exceeding the auto-ignition temperature of gases are all examples of ignition sources.

11. ERGONOMICS

11.1 Scope

This section on ergonomics is intended to provide information to increase safety awareness and use of safe practices in designing the human-machine interface to prevent ergonomic or musculoskeletal disorder injury/illness. Additional guidance will be provided that should be considered in the layout, workflow and movement of parts and material through the thermal spray installation. This should be included in the design of both the thermal spray booth, tooling/fixture to be utilized in the booth, coating materials and actual work steps.

11.2 Design Considerations

The overall intent is to reduce the potential of ergonomic injuries or illness via the following methods and in the same order of priority:

1. Engineering Design
2. Administrative Procedures
3. Personal Protective Equipment

Engineering Design – In the engineering of the equipment, ergonomics must be integrated into the design of: tooling, workstation layout, material movement, process, and maintenance activities. During this engineering phase, the opportunity exists to reduce and eliminate future injuries/illnesses due to ergonomics. **Consideration** must include, among other things, operator size, body position, reaches, ease of operation (force and repetition of motion) and weight. This list is numerous and it is recommended that an ergonomics checklist be developed/obtained and utilized. An example of an engineering design may be a new lever-type clamp to hold a part versus a manual twist clamp where the twisting motion is eliminated, thereby reducing the potential of an ergonomic injury due to the repetitive motion of the wrist/hand.

Administrative Controls – may be incorporated for existing controls measures where the equipment is already installed or where the new design may be economically unjustified. These types of controls are operating procedures that incorporate the same or similar ergonomic considerations into the task at hand. An example is use of a pneumatic air tool for grinding debris or overspray from a part versus using a file or emery cloth, which involves extended gripping, may be forceful and repetitive.

Personal Protective Equipment (PPE) – must be utilized throughout the workplace, however, there are specific tasks whereby PPE may be necessary to eliminate or reduce the potential for ergonomic type injuries/illnesses. Again consideration must be given to the task at hand and how PPE may be utilized. An example is the use of padded gloves to reduce vibration in certain power tools. Extended vibration may lead to an ergonomic injury/illness if not properly addressed.

Ideally, ergonomics should be addressed in the design; however, there are numerous equipment/processes in existence already. For those existing applications the other two controls are still available resources.

Material Movement

Consideration should be given to the movement of material into the workplace, in the workplace and out of the workplace. Consideration to include the handling of material so that the operator is not over extending himself/herself, frequency of motions, as in loading/unloading parts is minimized and lifting/bending and twisting is controlled to an acceptable practice.

Weight, Size and Shape of Workpieces

Consideration for the weight, size and shape of the workpiece must be factored into the ergonomic analysis. Many companies now have weight limits placed on individuals to reduce the injury potential. Those weight limits range from 30 to 100 pounds (13.6 to 45.4 kg). Remember size, shape and loading needs when performing the analysis.

Workpiece Preparation Requirements

What are the tasks needed for the preparation of parts and most importantly how are they accomplished? Is the operator able to face the work in a neutral position whether standing or sitting? Grasping the work with the hands or fingers, arms, hands, feet and leg placement while working, lighting, body or back position and repetition are critical in the ergonomics analysis.

Workspace or Workstation Layout

Consider the posture of the individual performing the work. Correct posture is also defined as the ears, shoulders and hips being in vertical alignment. The work needs to be close at hand, this is true whether the operator is standing or sitting. Less force is required when the work is within reach (12 to 18 inches (305 to 457 mm) of the body and at an acceptable elevation). Beyond that the work becomes awkward and injury potential increases.

11.3 Repetitive and Force of Operations

Consideration must include the frequency and force of the task. Performing a minor task over and over or performing a task with excessive force may lead to a cumulative trauma ergonomic injury/illness. Consider periodic breaks or job rotation as a means to reduce the stress from these tasks.

In summary, ergonomics simply means designing the workstation so that the task at hand may be accomplished without stressing the body to a point of injury. With proper forethought this may be accomplished utilizing the basic concepts mentioned above.