Plasma Cutting Technology: Theory and Practice

Student workbook

Powered by Hypertherm®

893410 – Revision C

Introduction

Welcome to the ***Plasma Cutting Technology: Theory and Practice*** course. Use this Student Workbook throughout the class to follow along with the instructor and participate in all of the activities and hands-on exercises.

About the designers of this course: Hypertherm designs and manufactures the world's most advanced plasma cutting systems for use in a variety of industries such as shipbuilding, manufacturing, and automotive repair. Its product line includes handheld and mechanized plasma systems and consumables, as well as CNC motion and height controls. Hypertherm systems are trusted for performance and reliability that results in increased productivity and profitability for tens of thousands of businesses. The New Hampshire based company's reputation for plasma innovation dates back over 40 years, to 1968, with Hypertherm's invention of water injection plasma cutting. The company, consistently named one of the best places to work in America, has more than 1,000 associates along with operations and partner representation worldwide. To learn more, please visit www.hypertherm.com.

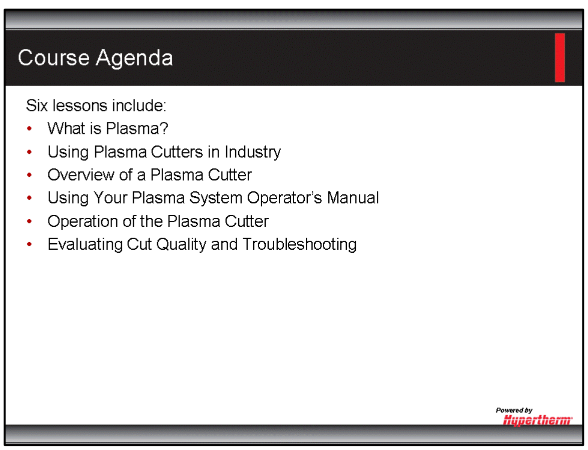
Course Overview

Session 1: What is Plasma?
Session 2: Using Plasma Systems in Industry
Session 3: Overview of a Plasma System
Session 4: Using Your Plasma System Operator's Manual
Session 5: Operation of the Plasma System
Session 6: Evaluating Cut Quality and Troubleshooting
Session 7: Theory Exam
Session 8: Freehand and Template Cutting
Session 9: Hole Piercing and Gouging #1
Session 10: Gouging #2 and Final Evaluations

Session 1: What is Plasma?

Introduction

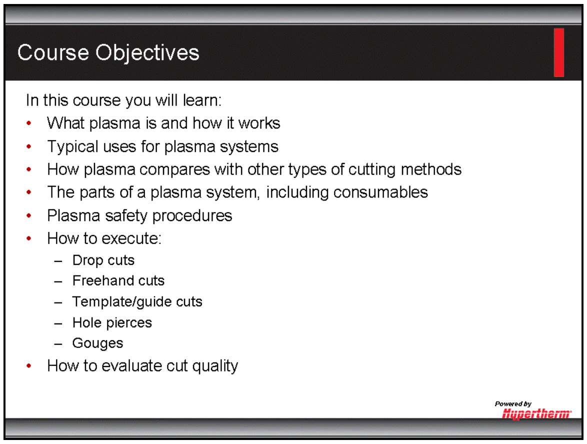
Slide 0: Lesson Title



Slide 1: Course Agenda

The course includes six lessons, each of which includes in-class activities:

1. What is Plasma?
2. Using Plasma Systems in Industry
3. Overview of a Plasma System
4. Using Your Plasma Cutter Operator's Manual
5. Operation of the Plasma System
6. Evaluating Cut Quality and Troubleshooting

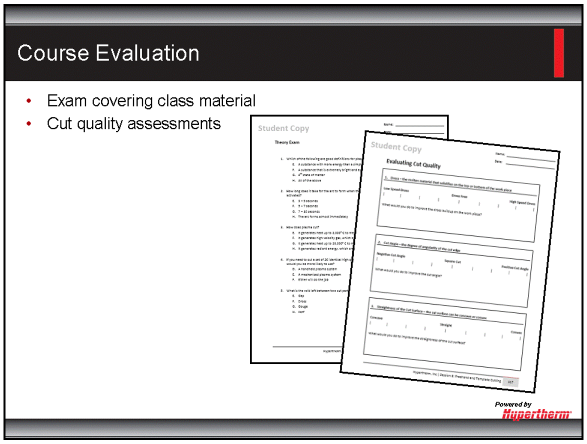


Slide 2: Course Objectives

Upon completion of this course, you will be able to:

- Demonstrate understanding of what plasma is and how it works.
- Identify industrial uses for plasma systems.
- Compare and contrast plasma with other cutting methods, including oxy-fuel and laser.
- Identify the parts of a plasma system, including consumables.
- Demonstrate understanding of plasma safety procedures.
- Demonstrate the ability to execute:
    - **Drop cuts**
    - **Freehand cuts**
    - **Template/guide cuts**
    - **Hole pierces**
    - **Gouges**
- Demonstrate the ability to evaluate the quality of cuts.

Bevel Cut:	The cutting technique that uses a tilted torch to produce an angle on the edge of parts being cut.
Drop Cut:	A cut that results in one section of the workpiece dropping away from the main piece.
Freehand Cut:	Cuts made without the benefit of a straight edge or template.
Gouging:	Removing metal from the surface of the plate without full penetration; used to remove old welds or prep a surface for welding.
Hole Pierce:	A method of starting a cut in which the arc plunges into and through the workpiece before cutting begins.
Template/Guide Cut:	Cuts made using a straight edge or template to guide the cut along a predefined path.

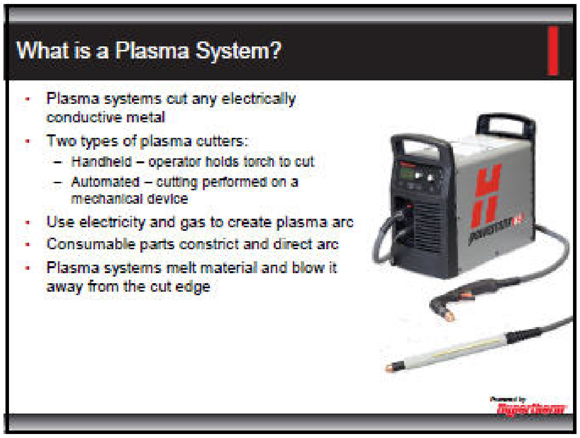


Slide 3: Course Evaluation

You will be evaluated based on two criteria:

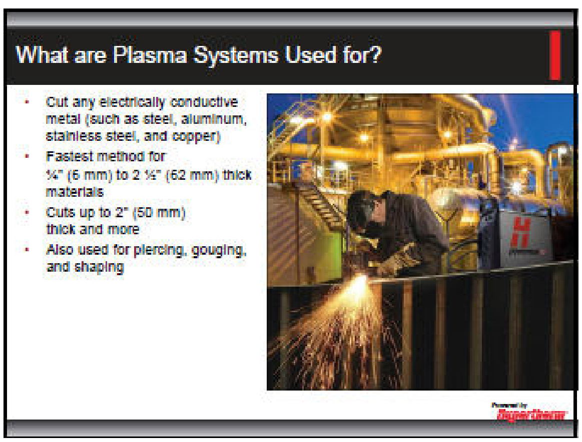
- A 30-question assessment based on the materials covered within the six lessons.
- Self- and instructor-evaluations of the cuts made with the plasma system.

What is a Plasma System



Slide 4: What is a Plasma System?

- Plasma systems are machines designed to cut various thicknesses of electrically-conductive metal.
- They range from handheld portable units to automated, table-mounted units.
- A plasma system uses electricity and gas to create a very high temperature (20,000° C) arc, also known as plasma.
- The consumable parts held by the **torch** work to constrict and direct the arc, which maximizes its efficiency at cutting metal.
- Plasma systems use the arc and the gas flow that shapes the arc to melt material and blow it away from the cut edge, respectively.



Slide 5: What Are Plasma Systems Used For?

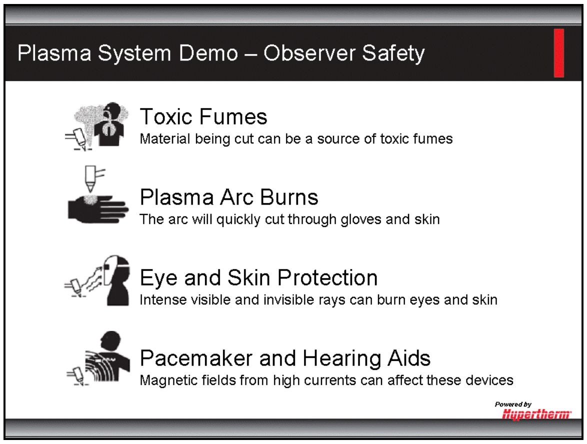
- Plasma systems can cut ***any*** electrically conductive metal; common materials include steel, aluminum, stainless steel, and copper.
- Plasma cutters are generally the fastest method for cutting materials between ¼" (6 mm) and 2 ½" (62 mm) in thickness.
- Typical plasma cutters can cut plate up to 2" (50 mm) thick. However, specialized industrial machines are available to cut even thicker materials.
- Plasma cutters are also used for piercing, gouging, and shaping (for example, bevel cuts).

Torch	The part of the plasma system that is used to perform the actual cutting.

Slide 6: Types of Plasma Systems

- Manual –-readily portable units often with a hand-held torch, with typical capacity of cutting up to 2" (5 cm) thick plate. Special straight torches allow these systems to be used on CNC cutting tables for certain applications.
- Mechanized – typically installed in a factory setting for high duty cycle use. Usually optimized for very high quality or high speed cutting, and some systems capable of cutting extremely thick materials.

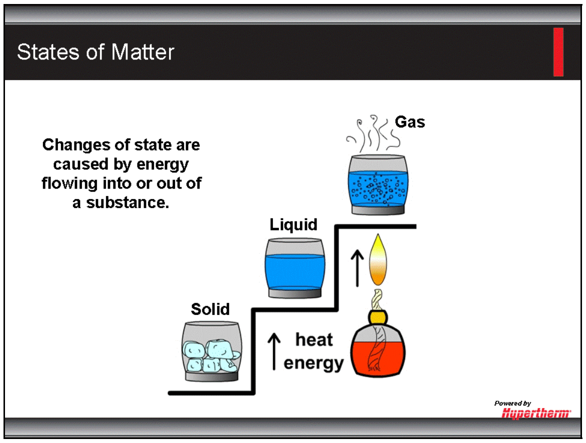
Plasma System Demonstration



Slide 7: Safety for Observers

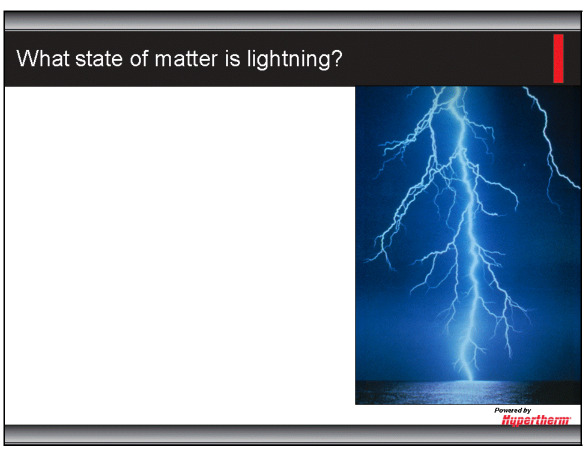
- **Toxic Fumes** – The material being cut can be a source of toxic fumes or gases that deplete oxygen. Metals that may release toxic fumes include, but are not limited to, stainless steel, carbon steel, zinc (galvanized), and copper. Metal can also be coated with substances that can release toxic fumes; they may include, but are not limited to lead, cadmium, and beryllium.
- **Plasma Arc Burns** – The plasma arc forms immediately when the torch switch is activated and will cut quickly through gloves and skin. Keep clear of the torch tip and cutting path, and never point the torch toward yourself or others.
- **Eye and Skin Protection** – Plasma arc rays produce intense visible and invisible (ultraviolet and infrared) rays that can burn eyes and skin. Use eye protection with appropriate lens shading and wear protective clothing, including gauntlet gloves, safety shoes, hat, flame-retardant clothing, and cuff-less trousers to prevent entry of sparks and slag. Remove any combustibles from your pockets before cutting.
- **Pacemaker and Hearing Aids** – Pacemakers and hearing aid operation can be affected by magnetic fields from high currents. Wearers of either device should consult a doctor before going near any plasma arc cutting and gouging operations.

What is Plasma?

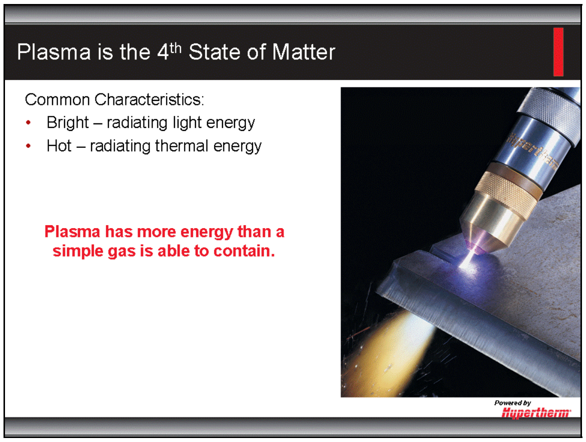


Slide 8: Plasma is a State of Matter

- Engineers use the term "state" to describe the physical form of a substance. Familiar examples of "states" are solid, liquid, or gas. Under the proper conditions, every element or chemical compound is capable of existing in these three standard states.
- When a substance changes state, the chemical make-up of the substance doesn't change, only its physical form changes.
- Changes in state are always caused by energy flowing into or out of a substance. Adding heat energy to a substance can increase its temperature and eventually cause it to change state.
- When heat energy is added to ice, the temperature increases, and it changes from a solid (ice) to a liquid (water). Add even more heat energy, and eventually the liquid will become a gas (steam).
- For most substances, lower energy states (solids) tend to be more dense and rigid than higher energy states (gases).



Slide 9: What state of matter is lightning?



Slide 10: Plasma is the 4th State of Matter

- The common characteristics of lightning and other plasmas are that they are bright (radiating light energy) and they are generally hot (radiating thermal energy).
- Plasma has more energy than a gas is able to contain – the molecules in plasma are breaking down; they are excited to a point beyond being a gas.
- This is why plasma is called the "4th State of Matter."

Name: ______________________________

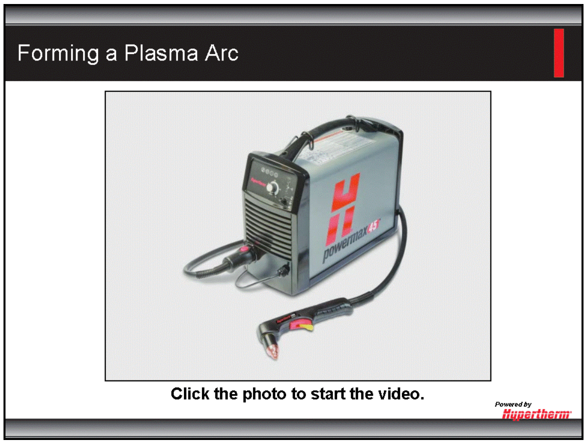
Date: ______________________________

Plasma Worksheet

Circle the real world substances that contain plasma.

Stars	Element on Electric Stove
Plasma Televisions	Aerosol Sprays
LEDs	Lightning
Steam	Fluorescent Bulbs
Smoke	Neon Lights
Auroras	Standard Light Bulbs

How is Plasma Created in a Plasma System?



Slide 11: How is Plasma Created in a Plasma System?

Handheld plasma torches receive gas and current flow from the power supply. They also hold consumable parts like the ones shown here, which help shape and maintain the plasma arc. At rest, the **electrode** and **nozzle** are in contact. Gas "blows back" the electrode, creating a separation in the current path. Electrons flow from the electrode and collide with neutral gas molecules. Each collision frees more electrons and creates positively charged gas molecules (ions). A cascading column of collisions is created; this column radiates thermal (or heat) energy and light energy (brightness) – this is plasma. The swirling gas inside the torch positions the arc precisely in the center of the electrode and pushes it out of the nozzle, where it can be used to cut or gouge metal.

A plasma arc cutter consists of a power supply and a torch. The power supply is very similar to a battery: it can provide a DC electrical current. The 'carriers' of this electrical current are called electrons, and electrons carry a negative charge. The electrons will flow from the negative terminal, around the circuit, and back to the positive terminal, forming a circuit.

There are two "consumable" parts connected into the circuit; they are called the electrode and the nozzle. "Consumable" simply means that they are slowly damaged by contact with the arc and by the heat of the plasma arc; they eventually wear out and need to be replaced. Other consumable parts on a torch include the swirl ring, the retaining cap, and the shield. The consumable parts control the size and shape of the plasma arc, and they can be optimized for specific applications or to emphasize a particular attribute like cut speed or cut quality. Some consumable sets are intended for cutting thin metal as artwork. These consumables are used with minimal standoff and cut a very narrow **kerf**. Other consumables are intended for making fast cuts in thicker material or gouging; these sets create a larger, wider arc.

In a plasma arc cutter the torch is connected into the circuit with the electrode at the negative terminal and the nozzle at the positive terminal. When the electrode and the nozzle are conductive and are touching each other current flows through them unimpeded; we need to create a gap in that circuit in order to make an electric arc. The power supply of a plasma arc cutter provides process gas (usually compressed air for handheld systems) to the torch. One way of creating an electric arc involves using the pressure of the process gas to separate the electrode and the nozzle from each other. Starting a plasma arc cutting torch by separating a shorted electrode and nozzle to form an arc is called "contact starting," because the electrode and nozzle started in contact with each other.

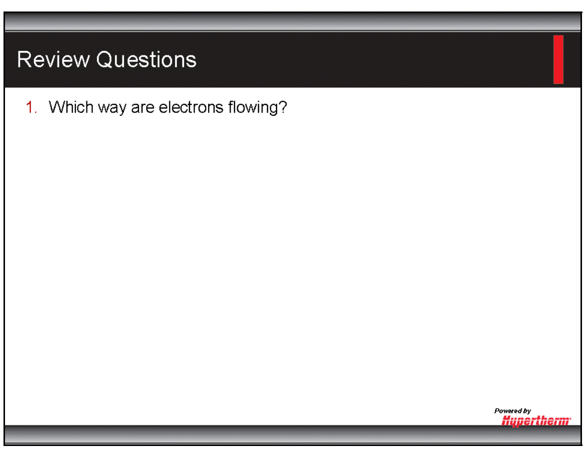
When the electrode and nozzle separate while already conducting current, the electrode emits a stream of electrons from its **hafnium** tip. As the electrons accelerate across the gap, they contact neutral gas molecules with enough force to strip more electrons free. Then the free electrons are re-accelerated toward the nozzle by the electric field and the positive ions are accelerated toward the electrode, making even more collisions possible. These collisions create more and more positive ions and free negative ions.

A cascading column of collisions forms; it radiates thermal energy and light energy – this is plasma – resulting in the formation of a spark. This spark is similar to the spark that is created by pulling the toaster plug from the wall when the toaster is running. The difference is that the spark from the toaster plug is momentary, but the plasma arc power supply is designed to feed power to the spark, instantaneously enlarging the spark into an arc. The arc that forms between the electrode and the nozzle is called the “pilot arc”. Gas from the power supply is used to force the pilot arc out of the nozzle orifice.

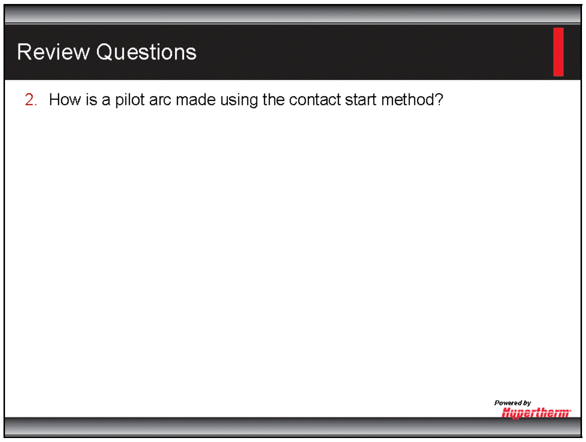
Once the pilot arc has been established, the workpiece needs to be brought into the circuit. The important step is converting the pilot arc (between the electrode and nozzle) into a “transferred arc” between the electrode and the workpiece. As the torch approaches the workpiece and the pilot arc contacts the plate, the nozzle and workpiece start to share the plasma current. The power supply forces all the current to go through the workpiece. The power supply increases the current to the cutting level and metal cutting begins.

Electrode:	The part of a consumable set that emits electrons in a steady stream to form the plasma arc.
Kerf:	The void left by the linear removal of material by any kind of cutting process; example: the width of the saw blade when cutting wood.
Nozzle	A consumable torch part containing a hole, or orifice, through which the arc passes.
Hafnium:	The metal used commonly as an electron emitter for air or oxygen plasma gases.

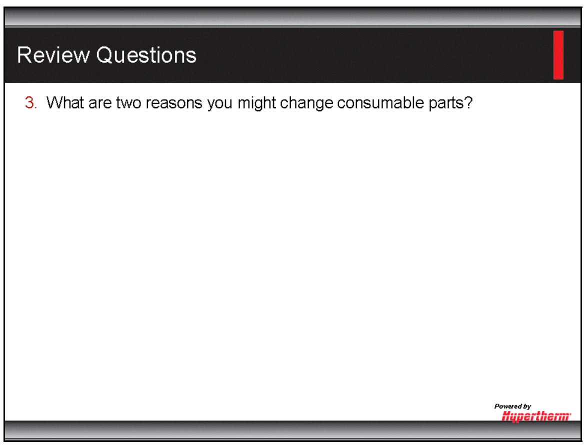
Slides 12 - 16: Review and Discussion



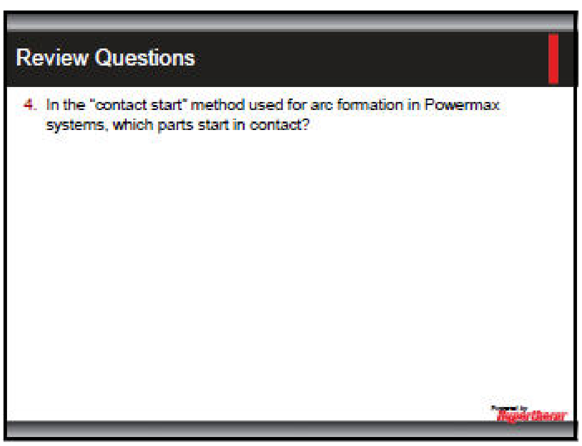
Slide 12: Which way are electrons flowing?



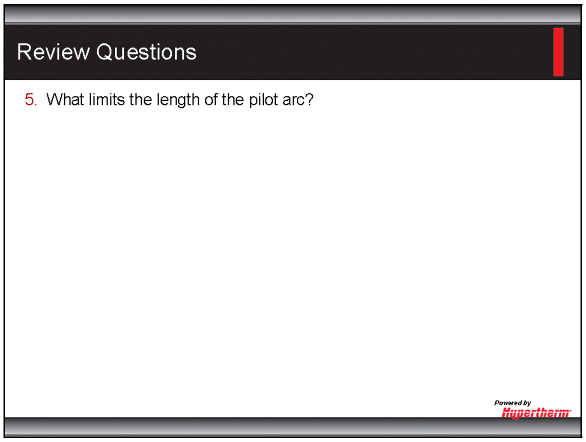
Slide 13: How is a pilot arc made using the contact start method?



Slide 14: What are two reasons you might change consumable parts?

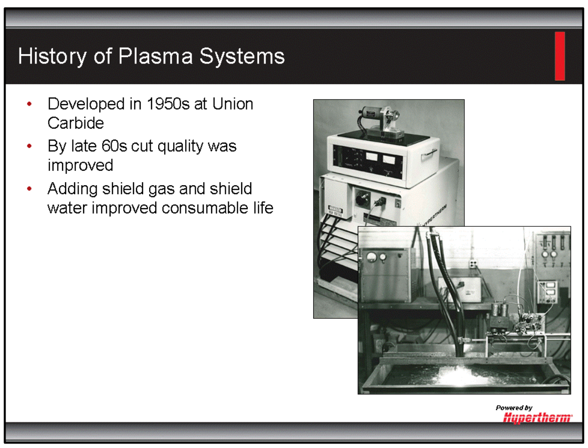


Slide 15: In the "contact start" method used for arc formation in Powermax systems, which parts start in contact?



Slide 16: What limits the length of the pilot arc?

History of Plasma Systems



Slide 17: History of Plasma Systems

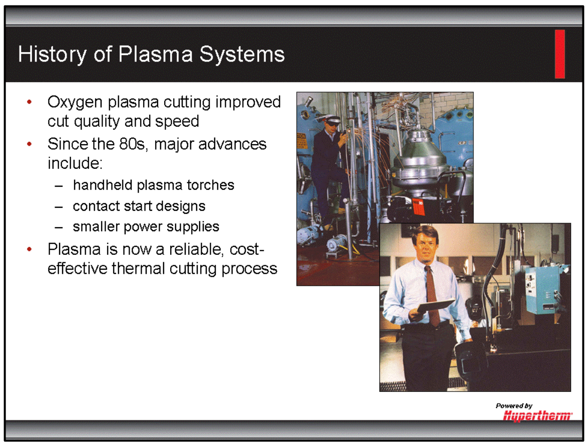
Plasma cutting was developed in the mid 1950s by a Union Carbide development engineer named Bob Gage. Union Carbide had developed a helium TIG welding torch called Heliarc for welding stainless steel and exotic alloys. Gage constricted the welding arc with a nozzle and increased the gas flow. By doing this, he created enough gas momentum and heat from the arc to cut through material. Gage got a patent for plasma arc cutting in 1957. Originally, plasma was used to cut stainless steel, which cannot be cut with oxyfuel. Stainless steel is a very small subset of the total steel production in the world; the vast majority is carbon steel and alloy steels. The cut quality and the reliability of the first plasma systems were poor, and in the late 50s and early 60s they met a very specific need for a relatively small market. Most customers would only purchase a plasma cutting system out of necessity.

By the late 60s, there were several companies researching plasma cutting. Stainless steel wasn't the only cutting possibility for plasma; it also offered a significant cut speed advantage over oxyfuel on carbon steel. Cut quality on carbon steel was not good, but if plasma ever became a viable option for cutting carbon steel the market for plasma would multiply quickly. Researchers needed to provide an answer to this question: why would someone buy plasma instead of oxyfuel to cut carbon steel? The solution was to focus research on improving cut quality.

One advance led to another. Addition of a shield gas improved the life of consumable parts. Switching that shield gas to shield water made consumable life still better. The use of water paved the way for water injection plasma cutting – swirling the shield water improved cut speed, cut quality, and consumable life. Though there were still significant challenges with **dross** formation, it appeared that plasma would be an alternative to oxyfuel for cutting carbon steel as well.

The next challenge was to make *consistently* high quality cuts with plasma. Even into the 70s plasma systems were expensive, unreliable, and specialized for cutting stainless steel. Consumable parts lasting more than 100 starts were rare. Operators were never certain what would happen when they pushed the start button. Differences in metal composition greatly affected cut quality. Plasma system manufacturers needed to find a cutting method that worked well on all varieties of carbon steel.

The solution was oxygen plasma cutting, which uses oxygen to create an additional chemical reaction with carbon steel. Cut quality improved, and operators were able to produce cuts with little or no dross. There was a tradeoff, however; oxygen made a hotter arc, which used up consumables very quickly. Customers liked the faster cut speeds and improved cut quality, but were frustrated with the loss of production time caused by constantly changing consumables. In 1983, that problem was addressed by water injection, which cooled the nozzle and made the consumables last longer.



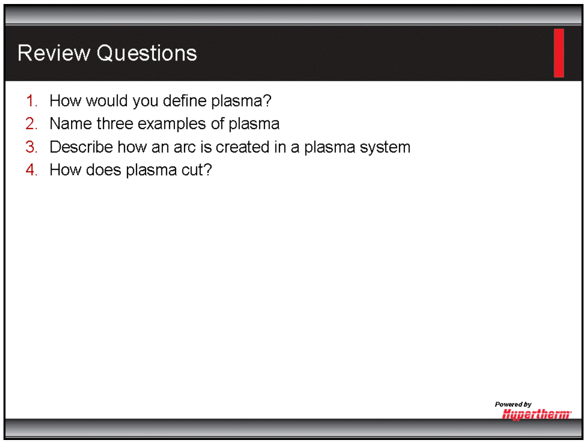
Slide18: History of Plasma Systems (cont.)

Since the 80s, there have been major advances in plasma cutting technology. Handheld plasma torches that used air as the plasma gas made plasma available to shops that did not have access to bottled gases. Shortly thereafter, the start mechanism for handheld plasma systems was redesigned, removing the need for high frequency starting. The new contact start design allowed for smaller parts. Reducing the size and number of parts in the power supplies made a huge difference in weight. By comparison, a handheld power supply in 1985 weighed nearly 400 pounds; today, there are handheld systems that only weigh 20 pounds!

25 years ago, some people thought there would be no more major improvements to the plasma cutting process. Now, over 50 years after its initial development, we know that plasma manufacturers are not close to exhausting the capability of plasma. While there has not been a significant technological development in the field of oxyfuel cutting in many years, plasma cutting continues to expand. The last 10 years alone have seen rapid advances in cut quality, consumable life, and versatility. Plasma is now a reliable, cost effective thermal cutting process. Current research is expected to further improve the capability of plasma.

Dross:	Re-solidified molten metal and oxides adhering to the top or bottom edge of the workpiece during thermal cutting.

Wrap-Up



Slide 19: Wrap-Up and Review Question Overview

Name: ______________________________

Date: ______________________________

Plasma Cutting Technology: Theory and Practice
Homework #1: What is Plasma?

1. How would you define plasma?

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2. Name three examples of plasma.

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3. Describe how an arc is created in a plasma system.

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4. How does plasma cut?

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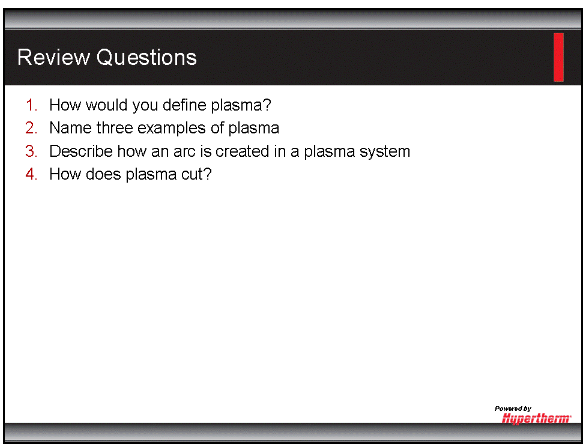
Session 2: Using Plasma Systems in Industry

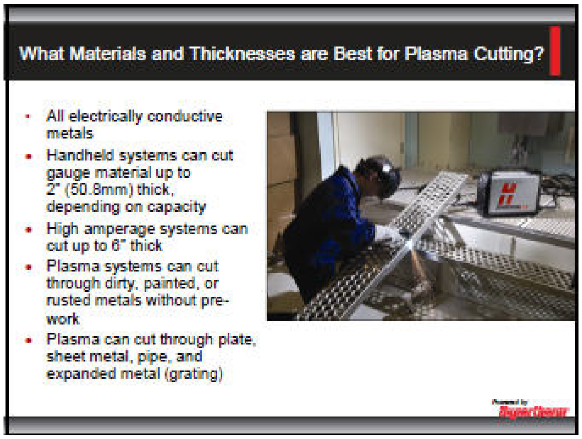
Introduction

Slide 0: Lesson Title



Slide 1: Review Questions

Suitable Applications for Plasma Cutting

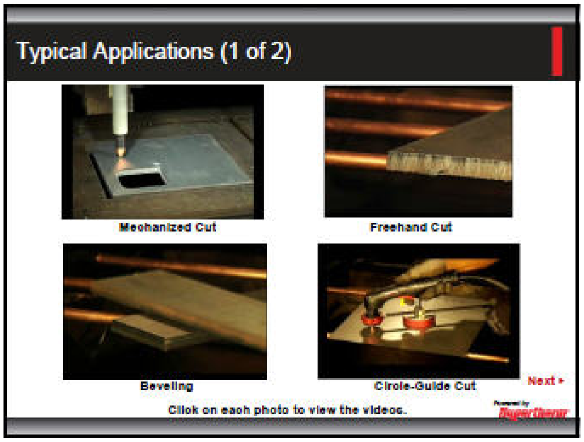


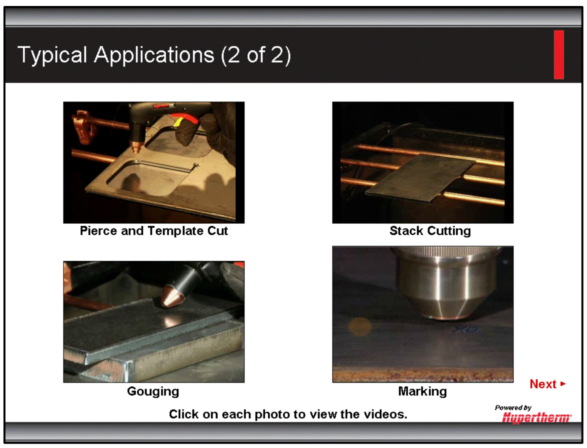
Slide 2: What Materials and Thicknesses are Best for Plasma Cutting?

- All electrically conductive metals – most frequently carbon steel, stainless steel, and aluminum.
- Handheld plasma systems can cut gauge material up to 2" (50 mm) thick, depending upon capacity.
- High amperage mechanized plasma systems are capable of cutting materials over 6" (15 cm) thick.

Plasma can cut through dirty, painted, or rusted metals without “pre-work” – preparation of the workpiece (the material being cut) before any cuts are made. Other cutting methods often involve prework, but with plasma all you need is good contact for grounding. Typical material forms cut with plasma include:

- Plate
- Sheet metal
- Pipe
- Expanded metal (grating)





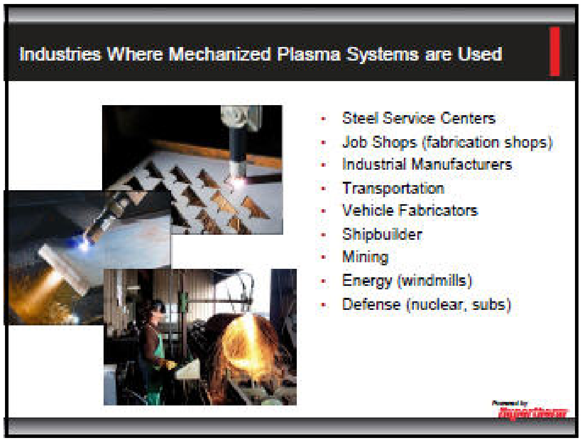
Slides 3 and 4: Typical Applications

- Cutting – typical cutting through a conductive workpiece with a hand held or machine (automated) torch:
    - Stack cutting – cutting through several pieces of plate stacked on top of one another.
    - Template cutting – cutting a workpiece using a shape or template as a guide.
    - Beveling – a cutting technique that produces an angle on the edge of the material being cut (such as for joining pieces of pipe).
- Piercing – starting a cut by plunging the arc into and through the workpiece (as compared to starting a cut at the edge of the work piece).
- Gouging – removing metal from the surface of the work piece without severing the piece in two (such as for weld preparation or removing an old weld).
- Marking – a low amperage process typically used to "write" part numbers or words on a part by removing a thin layer of the workpiece.

Slide 5: Industries Where *Handheld* Plasma Systems are Used

Some common uses for manual plasma systems include:

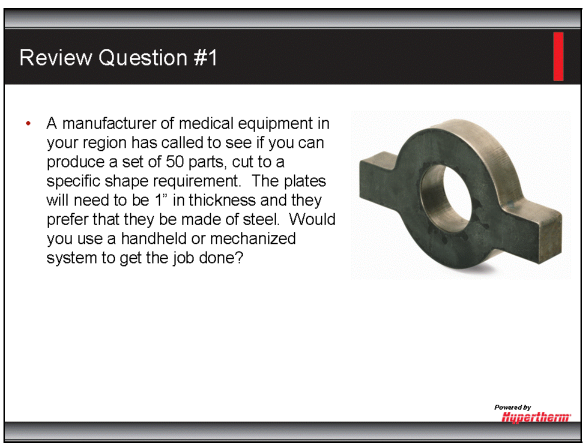
- General fabrication (pressure vessels, etc.) and manufacturing – food processing equipment, highway equipment, sign manufacturing, tank fabrication, and so on.
- Facility and equipment maintenance – railway maintenance, sawmill maintenance, for example.
- Structural steel building construction – wall and ceiling framing, floor and roof truss fabrication, roofing, siding, and decking installation.
- Shipbuilding.
- Container fabrication and repair.
- Energy – oil and gas, offshore rigs, pipelines.
- Vehicle repair and restoration – body and floor panel replacement, exhaust repair, frame repair, bracket removal.
- HVAC / mechanical contractors– duct fabrication and alteration, suspension bracket fabrication.
- Agricultural equipment repair – remove rusted panels, bevel cuts, gouging out of old welds for replacements, expanded metal fabrication.
- Ornamental metal fabrication – free form cutting, piercing and gouging, working with aluminum, ornamental fabrication.



Slide 6: Industries Where *Mechanized* Plasma Systems are Used

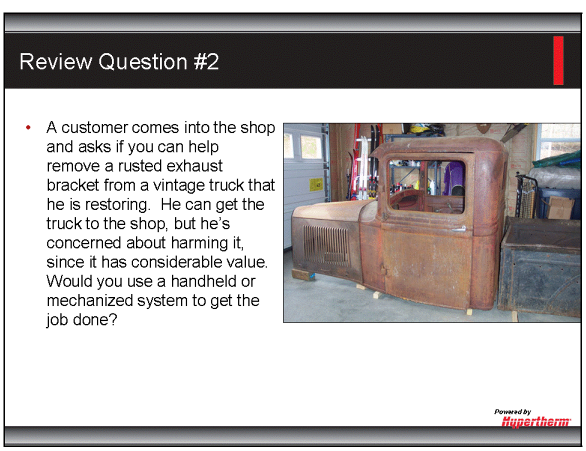
Some common uses for mechanized plasma systems include:

- Steel Service Centers
- Job Shops (Fabrication Shops)
- Industrial Manufacturers – heavy equipment for farming, agriculture, construction
- Transportation – trailer bodies, railway cars
- Vehicle Fabricators –panels, chassis parts
- Shipbuilder – thick panels, brackets,
- Mining
- Energy (Windmills)
- Defense – nuclear, subs



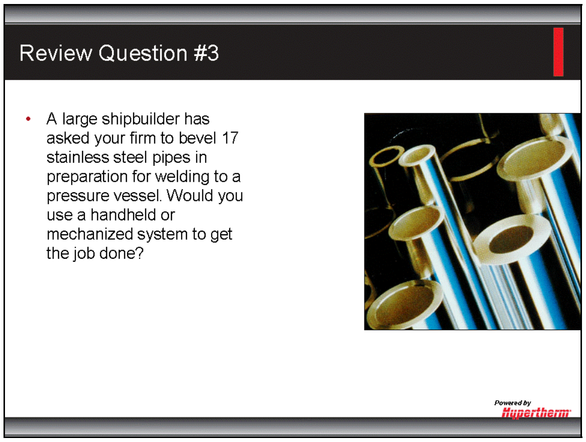
Slide 7: Review Question #1

A manufacturer of medical equipment in your region has called to see if you can produce a set of 50 parts, cut to a specific shape requirement. The plates need to be 1" (25 mm) carbon steel. How would you do it?



Slide 8: Review Question #2

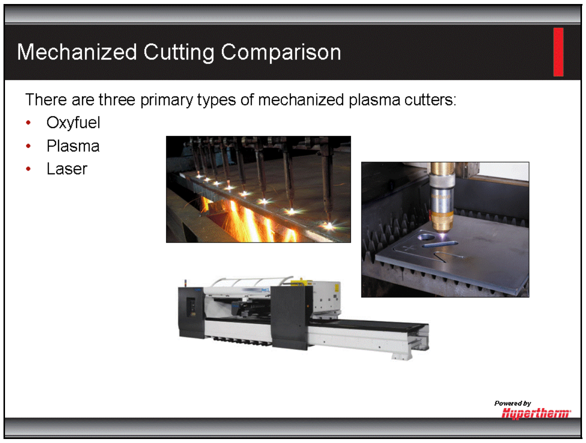
A customer comes into the shop and asks if you can help remove a rusted exhaust bracket from a vintage truck that he is restoring. He can get the truck to the shop, but he's concerned about harming it, since it has considerable value. How would you do it?



Slide 9: Review Question #3

A large shipbuilder has asked your firm to bevel 17 stainless steel pipes in preparation for welding to a pressure vessel. How would you do it?

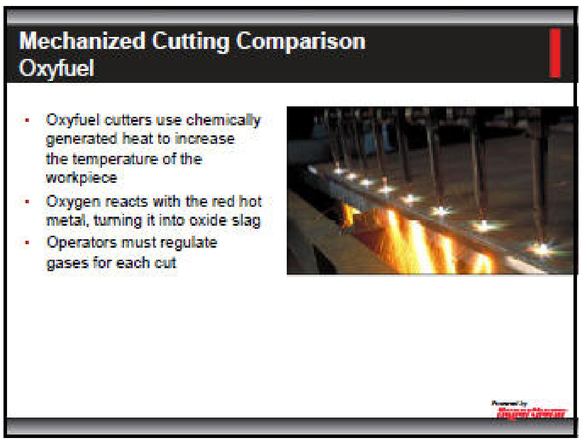
Mechanized Cutting Comparison



Slide 10: Mechanized Cutting Comparison

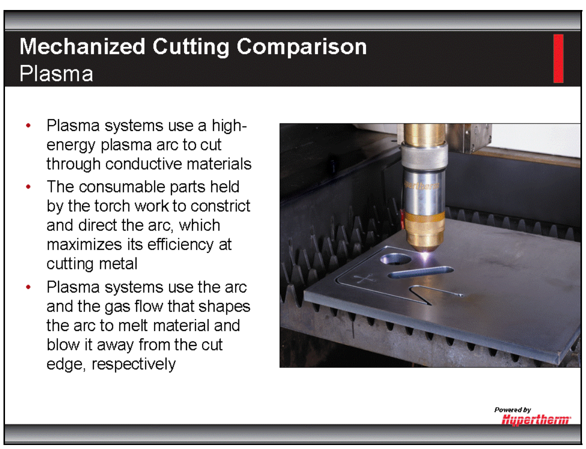
There are three primary types of mechanized plasma cutters:

- Oxyfuel
- Plasma
- Laser



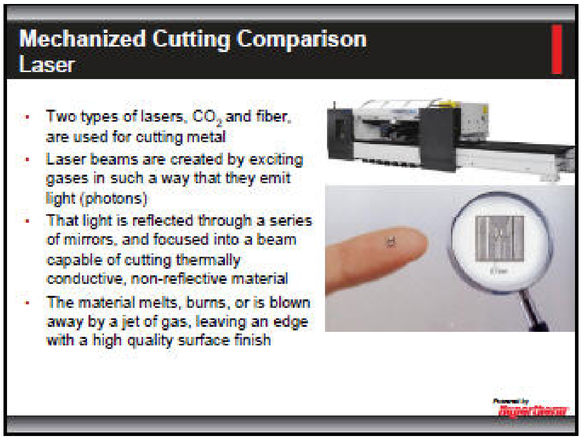
Slide 11: Oxyfuel

- Oxyfuel cutters use chemically generated heat to increase the temperature of the workpiece.
- Oxygen reacts with the red hot metal, turning it into oxide slag.
- Operators must regulate gases for each cut.



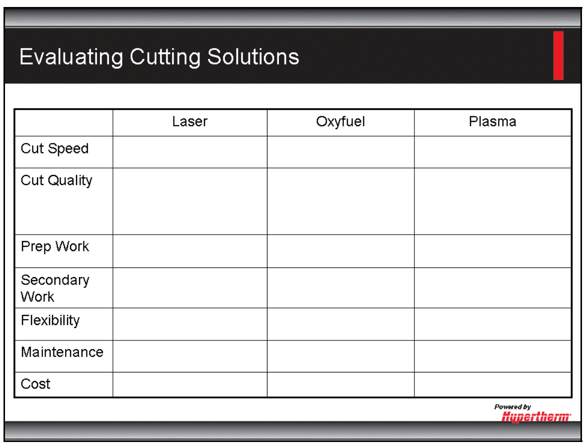
Slide 12: Plasma

- Plasma systems use a high-energy plasma arc to cut through conductive materials.
- The consumable parts held by the torch work to constrict and direct the arc, which maximizes its efficiency at cutting metal.
- Plasma systems use the arc and the gas flow that shapes the arc to melt material and blow it away from the cut edge, respectively.



Slide 13: Laser

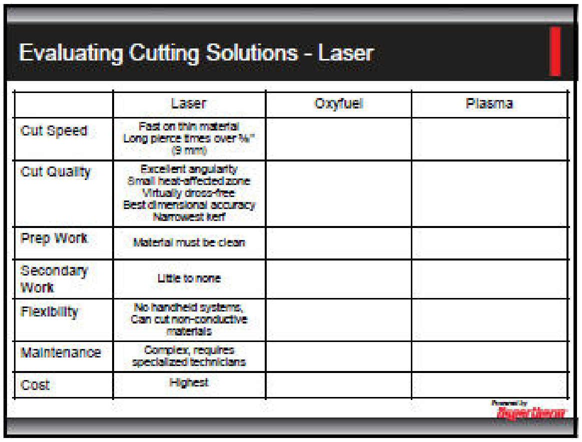
- Two types of lasers, CO_2 and fiber, are used to cut metal.
- Lasers transmit energy in the form of coherent photons. High intensity lasers transmit enough energy to cut non-reflective metal. Fiber lasers can cut some reflective metals as well.
- The material melts, burns, or vaporizes and is blown away by a jet of gas, leaving an edge with a high quality surface finish.
- The tightly-focused energy of a laser can produce very narrow kerf widths, especially on thin material.



Slide 14: Evaluating Cutting Solutions

When trying to decide what cutting solution to choose, look at several factors, including:

- Cut Speed – How fast is the actual cutting process?
- Cut Quality – How clean and square is the finished cut? How much dross remains following the cut? Is any secondary grinding required?
- Prep Work – How much cleaning and pre-work is needed before a material can be cut?
- Secondary Work – What is required after the cut is made and how much time does that take?
- Flexibility – Can the cutter accommodate different types of materials, types of cuts, and different material thicknesses?
- Maintenance – How hard is it to maintain/repair the system and can operators do it in-house?
- Cost – How much do the cutter and consumable parts cost?

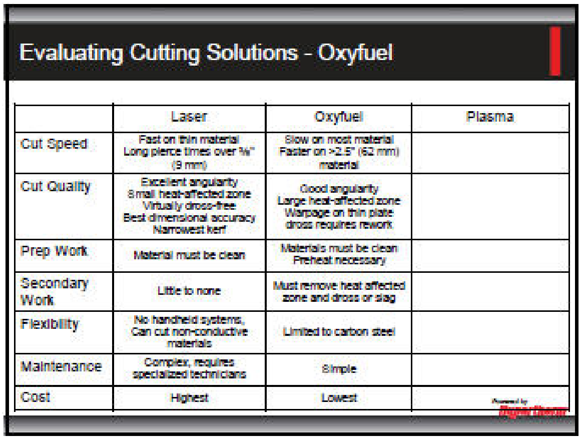


Evaluating Cutting Solutions - Laser

	Laser	Oxyfuel	Plasma
Cut Speed	Fast on thin material Long pierce times over ⅜" (9 mm)		
Cut Quality	Excellent angularity Small heat-affected zone Virtually dross-free Best dimensional accuracy Narrowest kerf		
Prep Work	Material must be clean		
Secondary Work	Little to none		
Flexibility	No handheld systems, Can cut non-conductive materials		
Maintenance	Complex, requires specialized technicians		
Cost	Highest		

Slide 15: Evaluating Cutting Solutions – Laser

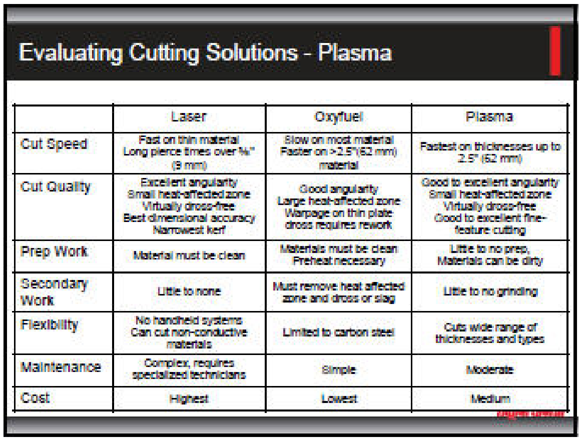
- Cut Speed: Very fast on thin material and slower on thicker materials; long pierce times on materials over ⅜" (9mm).
- Cut Quality: Excellent angularity, small heat-affected zone, virtually dross-free, and excellent dimensional accuracy with narrowest kerf.
- Prep Work: Material has to be clean for the laser to work.
- Secondary Work: Little to none.
- Flexibility: Pro: Laser is best at cutting thin carbon steel. Laser can do “common line cutting” – that is, it can produce final cuts in both directions with a single cut. This reduces/eliminates “skeletons”, which are the parts of metal sheets which are thrown away after parts are cut from them. Con: there are no hand-held laser systems, so the workpiece must lie on a table to be cut. Fiber laser can cut some reflective materials. Cutting reflective material (aluminum) with CO_2 laser requires pre-work to cover the material surface.
- Maintenance: Complex maintenance tasks require specialized technicians.
- Cost: Laser has the highest initial cost of the three – there are laser systems that cost over $1M.



	Laser	Oxyfuel	Plasma
Cut Speed	Fast on thin material Long pierce times over 3/8" (9 mm)	Slow on most material Faster on >2.5" (62 mm) material	
Cut Quality	Excellent angularity Small heat-affected zone Virtually dross-free Best dimensional accuracy Narrowest kerf	Good angularity Large heat-affected zone Warpage on thin plate dross requires rework	
Prep Work	Material must be clean	Materials must be clean Preheat necessary	
Secondary Work	Little to none	Must remove heat affected zone and dross or slag	
Flexibility	No handheld systems, Can cut non-conductive materials	Limited to carbon steel	
Maintenance	Complex, requires specialized technicians	Simple	
Cost	Highest	Lowest	

Slide 16: Evaluating Cutting Solutions – Oxyfuel

- Cut Speed: Slow cutting speeds across a wide range of thicknesses (faster than other systems on carbon steel over 2.5" or 62 mm); the pre-heat time increases pierce times significantly, decreasing overall cutting speed.
- Cut Quality: Good angularity, large heat-affected zone, warpage on thin plate, dross levels require rework.
- Prep Work: Oxyfuel cutters have to preheat the work piece prior to cutting. The cut area must be free of rust/dirt/paint before cutting. Operator must regulate gas flow for each torch, and oxyfuel tables often run multiple torches to compensate for slower cut speeds.
- Secondary Work: Operators may have to grind off the heat affected zone, which is larger than with other systems; this process can be time-consuming and difficult.
- Flexibility: Oxyfuel is limited to carbon steel and is not effective on stainless steel or aluminum.
- Maintenance: Simple maintenance requirements can often be performed by in-house maintenance groups
- Cost: Oxyfuel has the lowest initial cost of the three.



Evaluating Cutting Solutions - Plasma

	Laser	Oxyfuel	Plasma
Cut Speed	Fast on thin material Long pierce times over ⅜" (9 mm)	Slow on most material Faster on >2.5"(62 mm) material	Fastest on thicknesses up to 2.5" (62 mm)
Cut Quality	Excellent angularity Small heat-affected zone Virtually dross-free Best dimensional accuracy Narrowest kerf	Good angularity Large heat-affected zone Warpage on thin plate dross requires rework	Good to excellent angularity Small heat-affected zone Virtually dross-free Good to excellent fine-feature cutting
Prep Work	Material must be clean	Materials must be clean Preheat necessary	Little to no prep, Materials can be dirty
Secondary Work	Little to none	Must remove heat affected zone and dross or slag	Little to no grinding
Flexibility	No handheld systems Can cut non-conductive materials	Limited to carbon steel	Cuts wide range of thicknesses and types
Maintenance	Complex, requires specialized technicians	Simple	Moderate
Cost	Highest	Lowest	Medium

Slide 17: Evaluating Cutting Solutions – Plasma

- Cut Speed: Fastest on a wide range of thicknesses, up to 2.5" (62 mm).
- Cut Quality: Good to excellent angularity, small heat-affected zone, virtually dross-free, and good to excellent fine-feature cutting.
- Prep Work: Little to no prep required. Tolerant of paint/dirt/rust/oil on the work piece.
- Secondary Work: Little to no grinding; typically less than oxyfuel
- Flexibility: cuts a wide range of material thicknesses and types.
- Maintenance: Moderate maintenance requirements; many components are serviceable by in-house maintenance groups.
- Cost: Initial cost is typically between oxyfuel and laser, ranging from less than $2,000 up to $55,000.

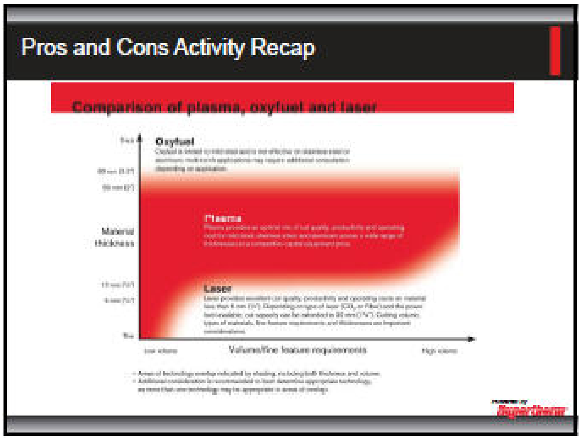
Name: ______________________________

Date: ______________________________

Pros and Cons Activity

Fill in the chart below by rating each cutting technology for each criteria with a 1, 2, or 3, where 1 is the best of the three, 2 is medium, and 3 is the worst.

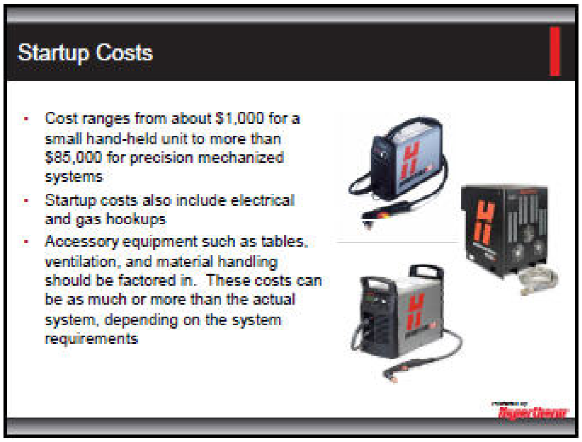
	Plasma	Oxyfuel	Laser
Cut Speed			
Cut Quality			
Prep Work			
Secondary Work			
Flexibility			
Maintenance			
Initial Cost			



Slide 19: Pros and Cons Activity Recap

- Oxyfuel has a low initial cost, but is limited to carbon steel and is not effective on stainless steel or aluminum.
- Plasma provides optimal mix of cut quality, productivity, and operating cost, for carbon steel, stainless, and aluminum across a wide range of thicknesses at a competitive capital and equipment price.
- Laser provides excellent cut quality and productivity on thin material. Laser technology has high capital equipment, running, and maintenance costs, therefore a high level of business volume is required to pay back the cost of the equipment.

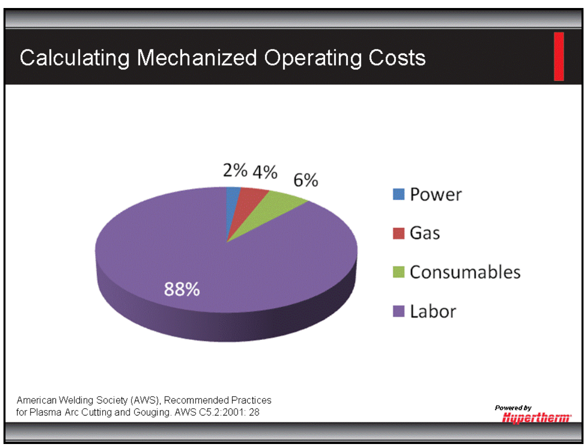
Cost/Benefit Analysis



Slide 20: Startup Costs

Review the startup costs associated with plasma systems:

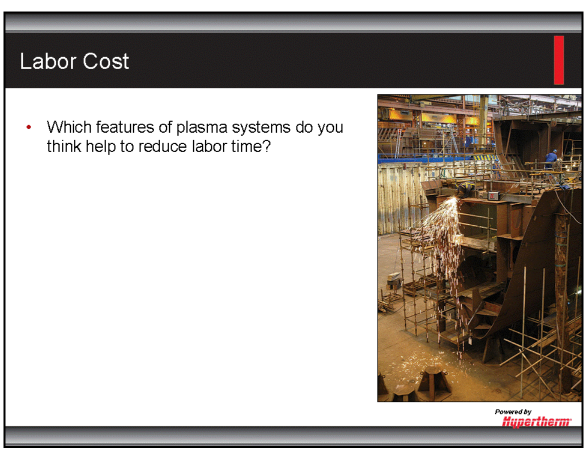
- Plasma systems range in cost from under $2,000 for a small hand-held unit to more than $55,000 for precision mechanized systems.
- Startup costs also include electrical and gas hookups.
- In addition, accessory equipment such as tables, ventilation, and material handling should be factored in. These costs can be as much or more than the actual system, depending on the system requirements.



Slide 21: Calculating Operating Costs

The total cost to operate any type of cutting equipment (following the initial equipment cost) is comprised of four primary costs, as shown below.

- Power to run the equipment (2%).
- Gas to produce the plasma (4%).
- Replacement parts, including torch consumables (6%).
- Labor required to operate and maintain the equipment, do required prep work, and complete any necessary secondary work (88%).



Slide 22: Labor Cost

Since we know that labor is by far the largest factor in calculating operating costs, consider the features of plasma systems that you think may help to reduce labor time required.

Slide23: Introduction to Case Study

Name: ______________________________

Date: ______________________________

Case Study for Calculating Labor Costs

Two shipbuilders in Virginia Beach are competing for a contract to provide scheduled maintenance on a large container ship. One section of the job involves removing rusted panels from the ship's hull and replacing them with new panels cut to fit from 1" (2.5 cm) thick steel plate. There are 100 panels on the ship that need to be replaced.

- ACME Incorporated uses a reliable oxyfuel cutter that they've had in the shop for years. Their labor costs are calculated at $100 per hour. Based on experience, they know that the following cutting tasks will be required to complete this job:

  Remove the rusted panels...10 minutes per panel

  Cut replacement panels from 1" (2.5 cm) steel plate .....25 minutes per panel

  Grind the replacement panels prior to welding.............10 minutes per panel

  Weld Replacement Panels...15 minutes per panel

- BRAVO Industries uses a plasma cutter. Their labor costs are calculated at $100 per hour. Based on experience, they know that the following cutting tasks will be required to complete this job:

  Remove the rusted panels...10 minutes per panel

  Cut replacement panels from 1" (2.5 cm) steel plate ....5 minutes per panel

  Weld Replacement Panels...15 minutes per panel

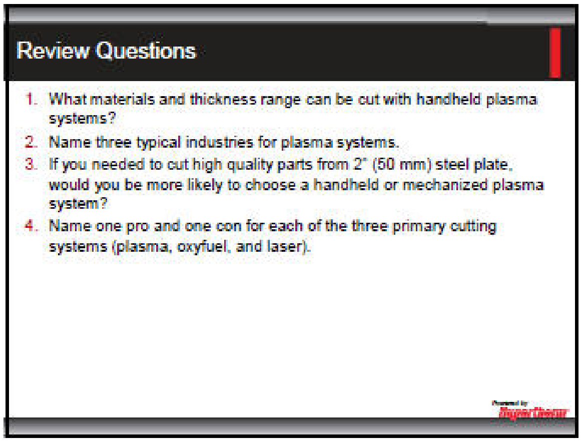
Calculate the labor costs required to perform this job and then answer the following questions:

1. What are the labor costs for ACME to perform the cutting required by this job?

2. What are the labor costs for BRAVO to perform the cutting required by this job?

3. Which company do you expect will get the job?

Wrap-Up



Slide 24: Wrap-Up and Review Question Overview

Name: ______________________________

Date: ______________________________

Plasma Cutting Technology: Theory and Practice
Homework #2: Using Plasma Systems in Industry

1. What materials and thickness range can be cut with handheld plasma systems?

2. Name three typical industries for plasma systems

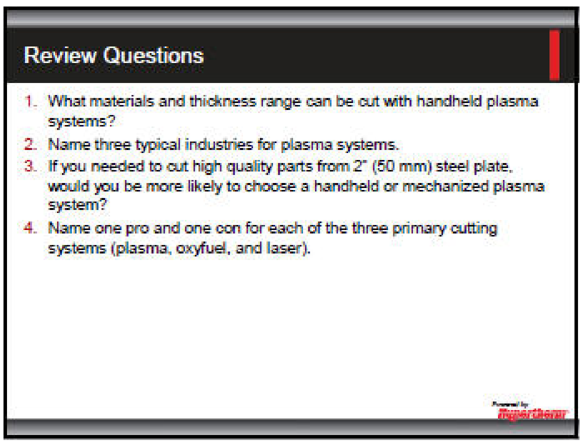
3. If you needed to cut high quality parts from 2" (50 mm) steel plate, would you be more likely to choose a handheld or mechanized plasma system?

4. Name one pro and one con for each of the three primary cutting systems (plasma, oxyfuel, and laser)

Session 3: Overview of a Plasma System

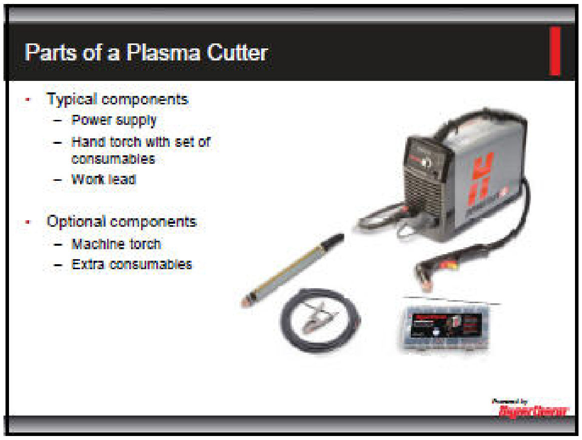
Introduction

Slide 0: Session Title



Slide 1: Review Questions

Parts of a Plasma System



Slide 2: Parts of a Plasma System

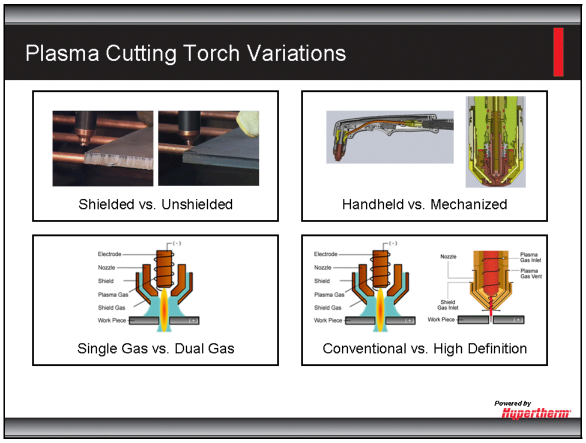
A plasma system will typically have the following components:

- Power supply
- Hand torch with set of consumables
- Work lead

It may also have these optional components, depending upon the manufacturer:

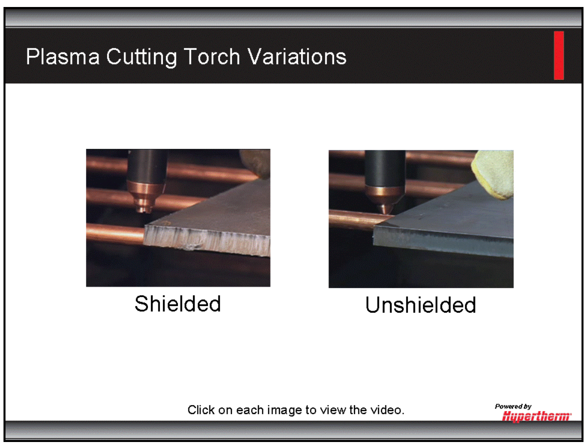
- Machine torch
- Extra consumables

Plasma Cutting Torch Variations



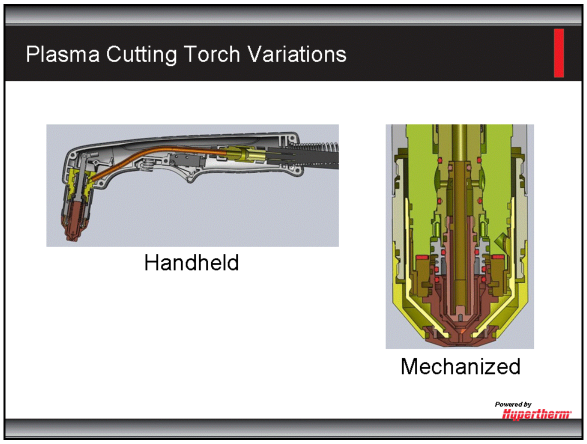
Slide 3: Plasma Cutting Torch Variations

- Shielded vs. Unshielded
- Handheld vs. Mechanized
- Single Gas vs. Dual Gas
- Conventional vs. High Definition



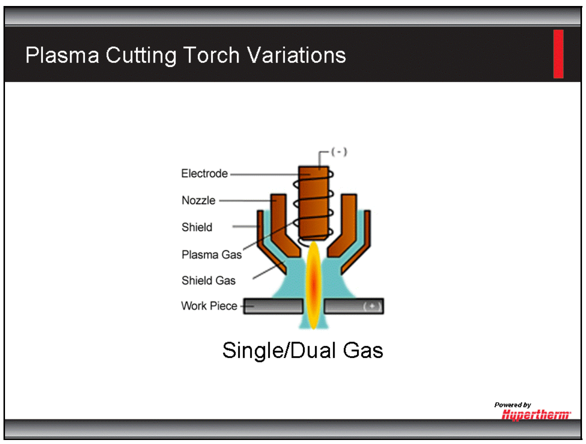
Slide 4: Shielded versus Unshielded

- The original plasma cutting consumable setup was unshielded; gas flowed between the electrode and nozzle forming a plasma.
- The nozzle shaped the plasma to cut through metal.
- Standoff is required when using unshielded consumables. The operator holds the nozzle 1/8" (3 mm) off the plate; if the torch touches the plate the consumables can be damaged or ruined.
- Some operators use unshielded consumables because they allow greater arc visibility in tight spaces.
- The shield serves several purposes:
  - Drag-tip shields allow the torch to rest directly on the work by setting the proper standoff distance.
  - Protects the consumables by keeping the nozzle electrically neutral.
  - Provides some secondary arc restriction.



Slide 5: Handheld versus Mechanized

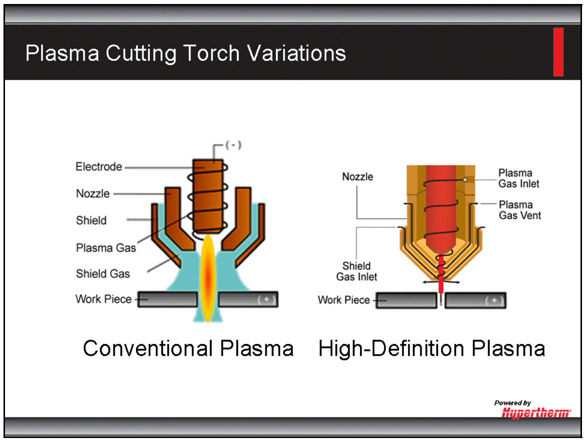
- Different starting mechanisms – handheld torches often have contact start designs, where mechanized torches may use either contact or high frequency starting.
- Hand torches are air cooled; mechanized torches may be water cooled.



Slide 6: Single Gas versus Dual Gas

- Most single gas and dual gas torches have a shield protecting the nozzle as well as a secondary flow of gas around the nozzle; the secondary flow is called "shield gas." The difference between single and dual gas designs is simple: if the plasma and shield gas are the same, it is single gas. If they differ, it is a dual gas.
- The selection of shield gas depends on the specific cutting application.
- Shield gas serves 3 purposes:
  - Cools the nozzle.
  - Keeps heat from radiating back up to the nozzle.
  - Helps remove molten material.
- In handheld systems, the plasma gas and shield gas usually flow from a single source; commonly, the gas will be compressed air or nitrogen. This is because:
  - Cut quality is less important than with mechanized systems.
  - Multiple gas cylinders and leads affect the portability of the system.

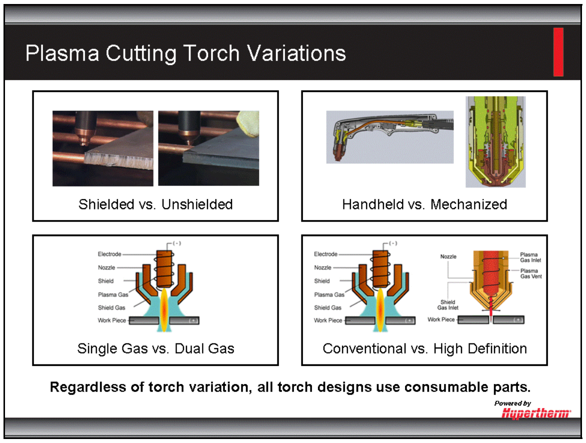
Many gas combinations are available, and are selected based on the equipment and the specific application; gas considerations are discussed in greater detail later in this session.



Slide 7: Conventional Plasma versus High Definition Plasma

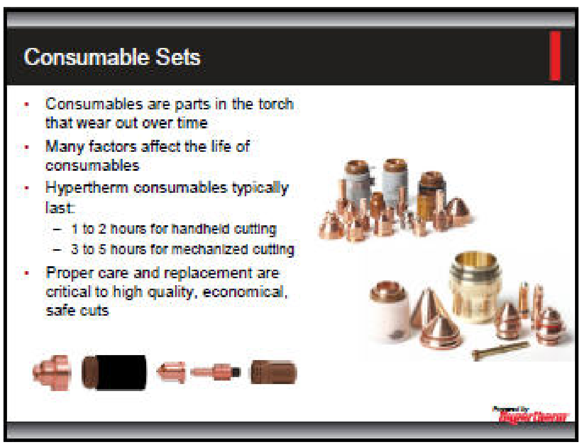
- Also called "Precision Plasma Cutting," high definition is the state-of-the-art mechanized arc constriction method.
- High definition provides extremely constricted plasma arcs that have increased energy density.
  - Energy density is achieved by high-flow vortex nozzles, high-velocity mixing chambers, magnetic fields, and other evolving technology.
  - Can be similar to laser cut quality in terms of angularity and dross.
  - Used only in mechanized applications.

Consumable Sets



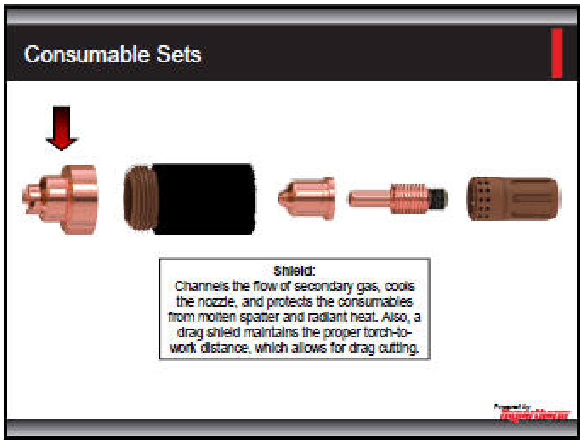
Slide 8: Plasma Cutting Torch Variations

- The common tie between all torch variations is their consumable parts.

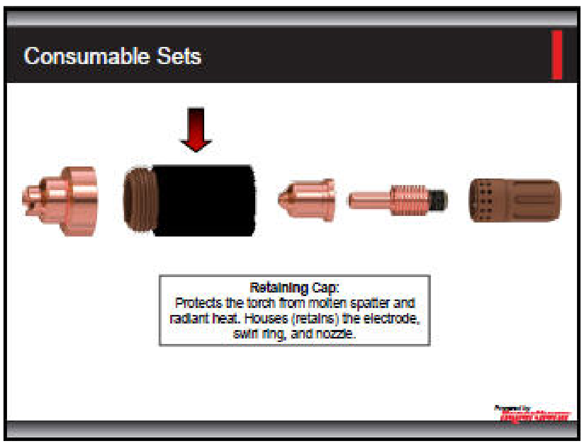


Slide 9: Consumable Sets

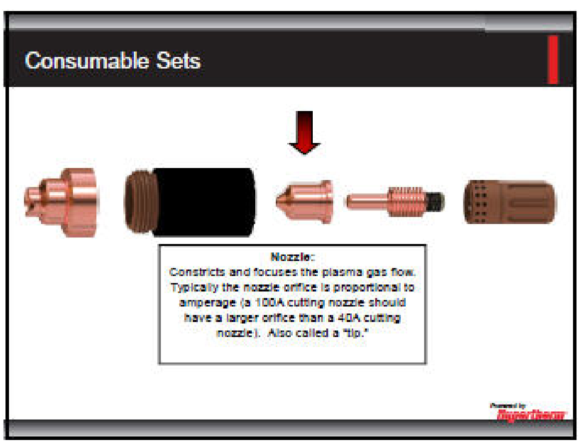
- Consumable sets are the parts in the torch that wear out over time.
- How often you need to change the consumables depends on a number of factors, including:
  - Thickness and type of material being cut.
  - Length of the average cut.
  - Air quality (the presence of oil, moisture, or other contaminants).
  - Whether you are piercing or edge-starting.
  - How well the proper torch-to-work distance is maintained with unshielded consumables.
  - Proper pierce height.
  - Which consumables you are using.
- For Hypertherm systems, a set of consumables lasts approximately 1 to 2 hours of actual “arc-on” time for handheld cutting and as much as 3 to 5 hours for mechanized cutting.
- Proper care and replacement of these parts are critical to high quality, economical, safe cuts.
- Always follow instructions for disconnecting power before inspecting or changing torch consumable parts.



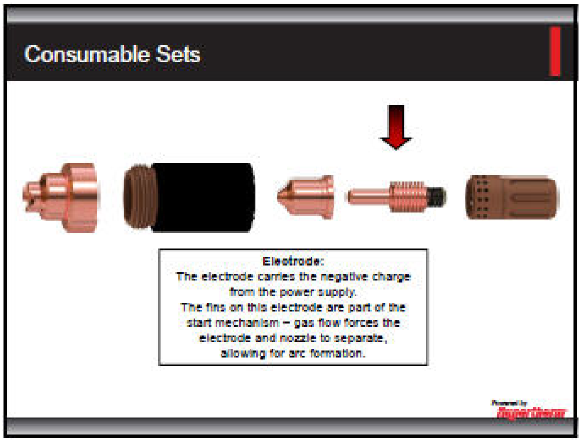
- **Shield (slide 10)** – channels the flow of secondary gas, cools the nozzle, and protects the consumables from molten spatter and radiant heat. This shield maintains the proper torch-to-work distance, which allows for drag cutting. The grooves in the tip of the shield allow the gas flow to blow molten material (and heat) away from the consumable set.



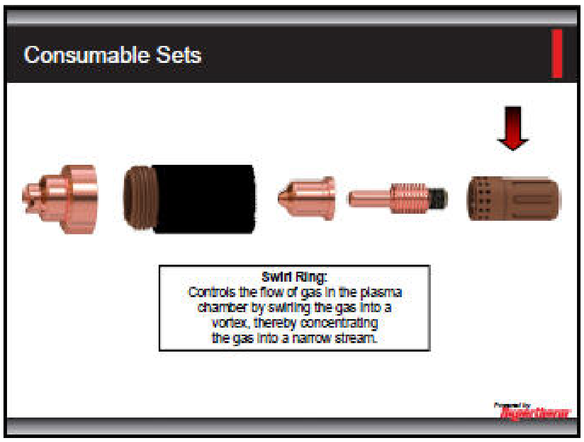
- **Retaining Cap (slide 11)** – protects the torch from molten spatter and radiant heat. Houses (retains) the electrode, swirl ring, and nozzle.



- **Nozzle (slide 12)** – constricts and focuses the plasma gas flow. Typically the nozzle orifice is proportional to amperage. The nozzle of a 100A machine will have a larger orifice than the Powermax45 (45A). Also note that there are special gouging nozzles, which have a larger orifice. Operators will lower the gas pressure, which produces less concentrated, wider plasma arc.



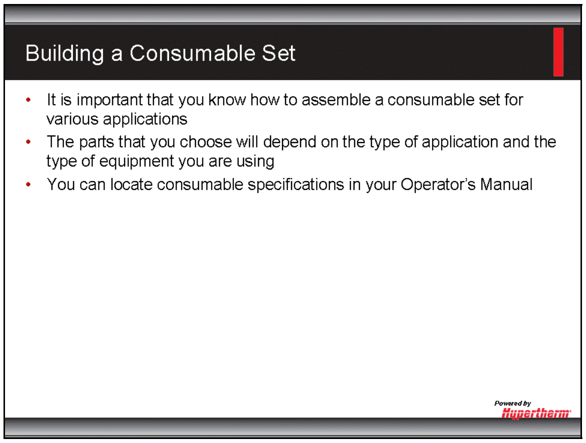
- **Electrode (slide 13)** – copper with a conductive insert (hafnium); the electrode carries the negative charge from the power supply. The fins on this electrode are part of the start mechanism – gas flow forces the electrode and nozzle to separate, allowing for arc formation.



- **Swirl Ring (slide 14)** – controls the flow of gas in the plasma chamber. Notice that the holes in the swirl ring are slanted to swirl the gas into a vortex (tornado), thereby concentrating the gas into a narrow stream.

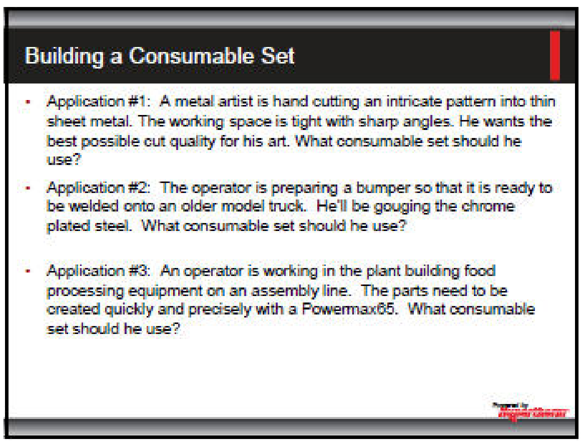
  When assembled, the holes in the swirl ring are below the fins on the electrode. When gas is forced through those holes, it pushes against the fins on the electrode, forcing it apart from the nozzle. This motion, called "blowback," is what allows for arc formation in the Powermax45 and Powermax65 contact start method.

Building a Consumable Set



Slide 15: Building a Consumable Set

- It is important that students know how to assemble a consumable set for various applications.
- The parts that you choose will depend on the type of application and the type of equipment you are using.
- You can locate the consumable specifications in your Operator's Manual.



Slide 16: Building a Consumable Set

- Work in teams of 3. One student works in the manual to identify the appropriate parts, one student assembles the parts, and the third student checks their work to make sure it is correct. Rotate roles for each of the three activities below.
- Open your Powermax65 manual to Section 3. This section includes the consumable options you will need to use to build an appropriate consumable set.
- You have 3 - 4 minutes to build an appropriate consumable set for each of these scenarios. Fill out the worksheet (provided on the following page) for each scenario.

Name: ______________________________

Date: ______________________________

Plasma Cutting Technology: Theory and Practice
Building a Consumable Set

Application #1: A metal artist is hand cutting an intricate pattern into thin sheet metal. The working space is tight with sharp angles. He wants the best possible cut quality for his art. What consumable set should he use?

Consumable Set: ____

Consumables: Part: ________________________ Number: ________________________

Part: ________________________ Number: ________________________

Part: ________________________ Number: ________________________

Part: ________________________ Number: ________________________

Part: ________________________ Number: ________________________

Application #2: The operator is preparing a bumper so that it is ready to be welded onto an older model truck. He'll be gouging the chrome plated steel. What consumable set should he use?

Consumable Set: ____

Consumables: Part: ________________________ Number: ________________________

Part: ________________________ Number: ________________________

Part: ________________________ Number: ________________________

Part: ________________________ Number: ________________________

Part: ________________________ Number: ________________________

Application #3: An operator is working in a plant, building food processing equipment on an assembly line. The parts need to be created quickly, but precisely, with a Powermax65. What consumable set should he use?

Consumable Set: ____

Consumables: Part: ________________________ Number: ________________________

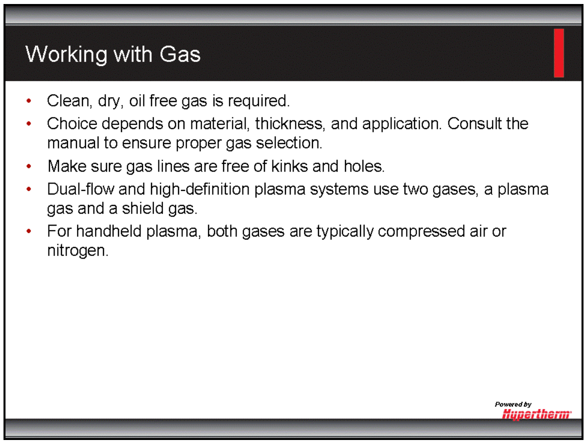
Part: ________________________ Number: ________________________

Part: ________________________ Number: ________________________

Part: ________________________ Number: ________________________

Part: ________________________ Number: ________________________

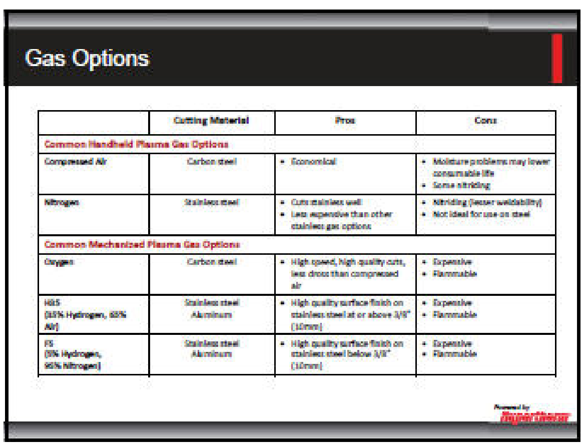
Gas Considerations



Slide 17: Working with Gas

Review the following important considerations when working with gas in a plasma system:

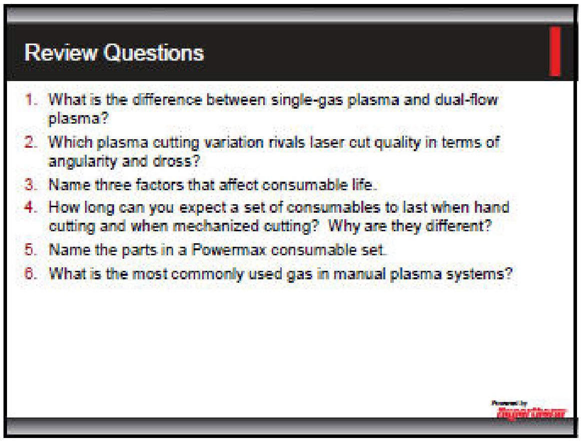
- Clean, dry, oil free gas is required.
- Mechanized plasma operators use a variety of gases; their choice depends on material, thickness, and application. Consult the operator manual to ensure proper gas selection.
- Make sure gas lines are free of kinks and holes. A drop in gas pressure may affect cut quality or cause a loss of start.
- Dual-flow and high-definition plasma systems use two gases, a plasma gas and a shield gas, to provide better cut quality and consumable life. For handheld plasma, both gases are typically compressed air or nitrogen.



Slide 18: Gas Options

The table shows the four most common gases used in plasma systems, along with general pros and cons for each. Review the chart with the class.

Wrap-Up



Slide 19: Wrap-Up and Review Question Overview

Name: ______________________________

Date: ______________________________

Plasma Cutting Technology: Theory and Practice
Homework #3: Overview of a Plasma System

1. What is the difference between single-gas plasma and dual-flow plasma?

____

____

____

____

2. Which plasma cutting variation rivals laser cut quality in terms of angularity and dross?

____

3. Name three factors that affect consumable life.

____

____

____

4. How long can you expect a set of consumables to last when hand cutting and when mechanized cutting? Why are they different?

____

5. Name the parts in a Powermax consumable set.

____

____

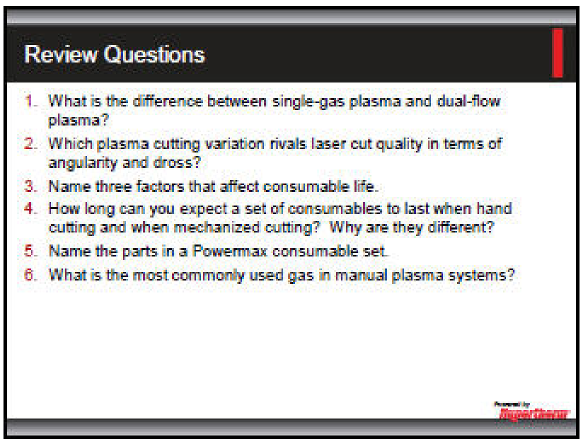
6. What is the most commonly used gas in manual plasma systems?

____

Session 4: Using Your Plasma System Operator's Manual

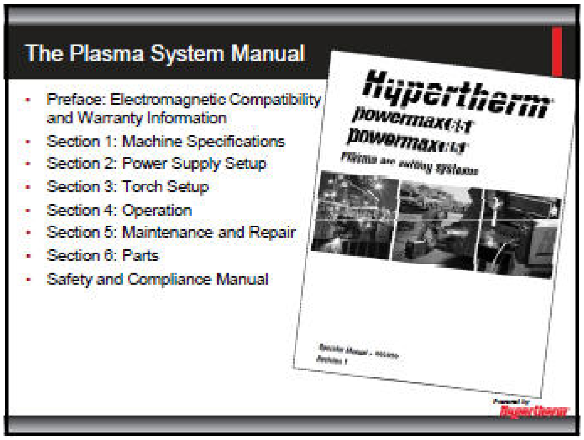
Introduction

Slide 0: Title Slide



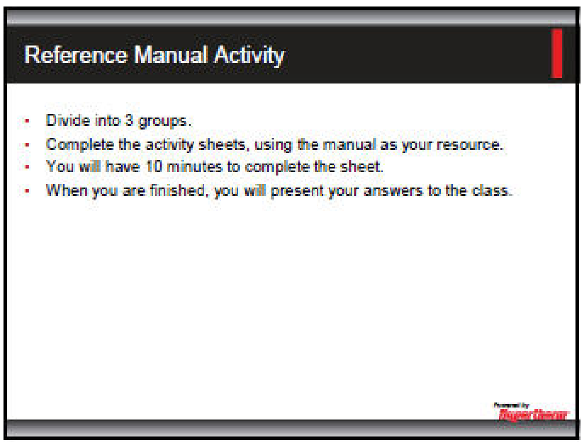
Slide 1: Review Questions

The Plasma System Manual



Slide 2: The Plasma System Manual

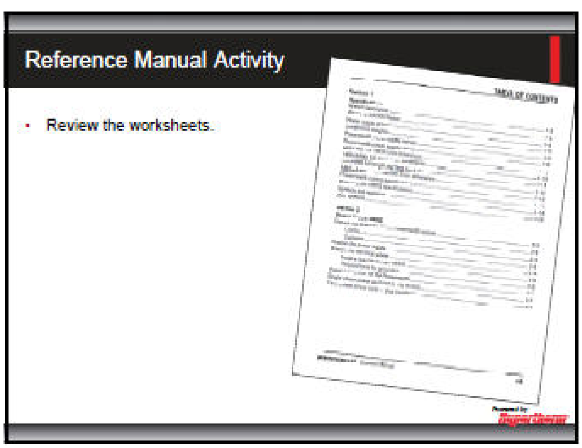
The manual should serve as the operator's first resource for information on the plasma system.



Slide 3: Reference Manual Activity

Use the Powermax65 manual to answer a series of questions.

- Divide into 3 groups. Pass out the three activity worksheets – one to each group.
- Each group should have at least one copy of the Powermax65 manual.
- Complete the activity sheets, using the manual and the Safety and Compliance Manual as resource tools.
- You have 10 minutes to complete the sheet.



Slide 4: Reference Manual Activity

Review your worksheets with the class before we move on to the next topic – safety.

Name: ______________________________

Date: ______________________________

Reference Manual Activity Sheet #1

You are working in an auto body shop in which a variety of repairs are required on a daily basis. The shop just purchased a Powermax65, and they intend to use it for all types of handheld cuts. You will need to set it up and teach your co-workers how to use the machine.

Answer these questions to get started on your task. You'll have 10 minutes to complete this worksheet. Answer each question in the space provided and be sure to include the page number in the manual where you found the information. When you are finished, you will be asked to present your answers to the group, explaining how and where you found the information within the manual.

Page #

1. Section 1: Machine Specifications – What types of gas input does the Powermax65 take? __________

   ____

2. Section 3: Torch Setup – Choose the appropriate shielded consumables for hand-cutting carbon steel. __________

   ____

3. Section 5: Maintenance and Repair – When you turn on the cutter, the fault LED illuminates and the fault code 0-50 displays on the LCD screen. What does that mean? __________

   ____

4. Section 4: Operation – The first cut you'll try is a piece of 5 mm plate. Where should the mode switch be set and what is this mode called? __________

   ____

5. Section 3: Torch Setup – You're asked to remove an existing weld. What shield part number would you use? __________

   ____

6. Section 5: Maintenance and Repair – The arc doesn't transfer to the work piece when you make a cut. What should you do? __________

   ____

Name: ______________________________

Date: ______________________________

Reference Manual Activity Sheet #2

You are working in an HVAC shop, primarily fabricating and altering duct work. Your boss just asked you to look over a new Powermax65 and be prepared to show your co-workers how to use the machine.

Answer these questions to get started on your task. You'll have 10 minutes to complete this worksheet. Answer each question in the space provided and be sure to include the page number in the manual where you found the information. When you are finished, you will be asked to present your answers to the group, explaining how and where you found the information within the manual.

Page #

1. Preface – How long is the warranty on the power supply? __________

   ____

2. Safety and Compliance Manual – For eye protection, what is the minimum protective shade number for the Powermax45? __________

   ____

3. Safety and Compliance Manual – Should you turn the power off before disassembling the torch? __________

   ____

4. Section 1: Machine Specifications – How much does a CSA Powermax65 weigh? __________

   ____

5. Section 3: Torch Setup – What is the Best Quality cut speed (mm/min) for cutting 10 mm aluminum with shielded consumables? __________

   ____

6. Section 5: Maintenance and Repair – When would you replace the electrode? __________

   ____

Name: ______________________________

Date: ______________________________

Reference Manual Activity Sheet #3

You are working for a custom metal fabricator that makes all types of parts to be used in manufacturing. They recently purchased a new Powermax65 plasma system and intend to use it for both mechanized and hand cutting. You will need to set it up and teach your co-workers how to use the machine.

Answer these questions to get started on your task. You'll have 10 minutes to complete this worksheet. Answer each question in the space provided and be sure to include the page number in the manual where you found the information. When you are finished, you will be asked to present your answers to the group, explaining how and where you found the information within the manual.

Page #

1. Preface – How long are the factory supplied torch parts warranted? ___________

   ____

2. Section 1: Machine Specifications – What is the mechanized pierce capacity of the Powermax65? ___________

   ____

3. Section 4: Operation – Which is easier when hand cutting – pushing the torch or pulling/dragging it? ___________

   ____

4. Section 4: Operation – You are asked to remove an existing weld. What is the recommended angle for gouging? ___________

   ____

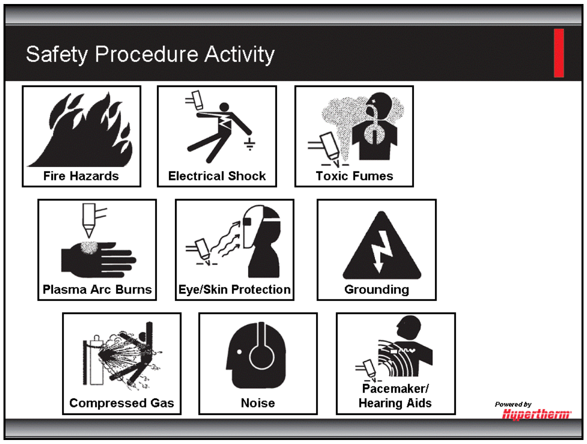
5. Section 4: Operation –What do you do with the hand clamp? ___________

   ____

6. Section 5: Maintenance and Repair – The power LED is blinking and fault code 0-13 shows on the screen. What does this mean? ___________

   ____

Safety Procedures

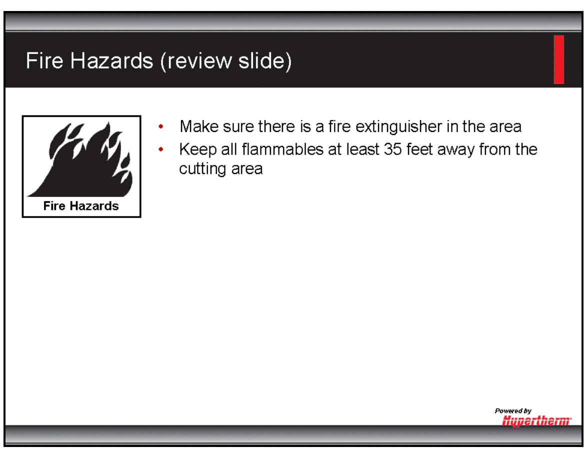


Slide 5: Safety Procedure Activity

There are 9 main safety topics covered in the manual, including the following:

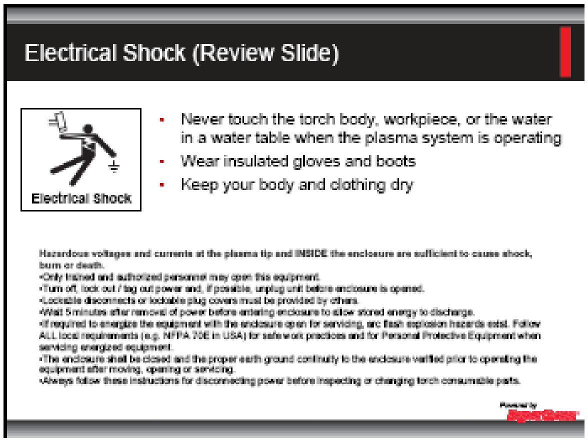
Fire Hazards	Electrical Shock
Plasma Arc Burns	Eye and Skin Protection
Compressed Gas	Noise

- Split the class into small groups and assign each group one safety topic. If you have a small class you may want to combine topics as follows:
  1. Fire Hazards
  2. Electrical Shock
  3. Toxic Fumes
  4. Compressed Gas
  5. Grounding, Noise, and Pacemaker/Hearing Aids
  6. Plasma Arc Burns and Eye/Skin Protection
- Take 5 minutes to review the safety information for your topic(s) and then be ready to present their findings to the class.



Slide 6: Fire Hazards

- Make sure there is a fire extinguisher in the area.
- Keep all flammables at least 35 feet away from the cutting area.



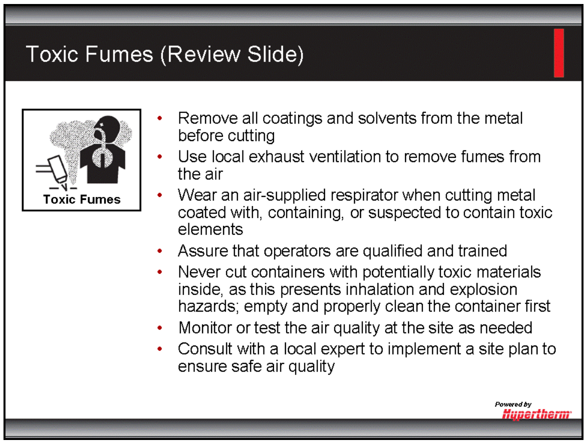
Slide 7: Electrical Shock

Touching live electrical parts can cause a fatal shock or severe burn. Operating the plasma system completes an electrical circuit between the torch and the workpiece; the workpiece and anything touching the workpiece are part of the electrical circuit.

- Never touch the torch body, workpiece, or the water in a water table when the plasma system is operating.
- Wear insulated gloves and boots.
- Keep your body and clothing dry.

Hazardous voltages and currents at the plasma tip and INSIDE the enclosure are sufficient to cause shock, burn or death.

- Only trained and authorized personnel may open this equipment.
- If power source is cord & plug connected, turn off power and unplug power source before opening the enclosure.
- If power source is permanently connected, turn off and lockout / tagout power before opening enclosure.
- Wait 5 minutes after removal of power before entering enclosure to allow stored energy to discharge.
- If required to energize the equipment with the enclosure open for servicing, arc flash explosion hazards exist. Follow ALL local requirements (e.g. NFPA 70E in USA) for safe work practices and for Personal Protective Equipment when servicing energized equipment.
- The enclosure shall be closed and the proper earth ground continuity to the enclosure verified prior to operating the equipment after moving, opening or servicing.
- Always follow these instructions for disconnecting power before inspecting or changing torch consumable parts.

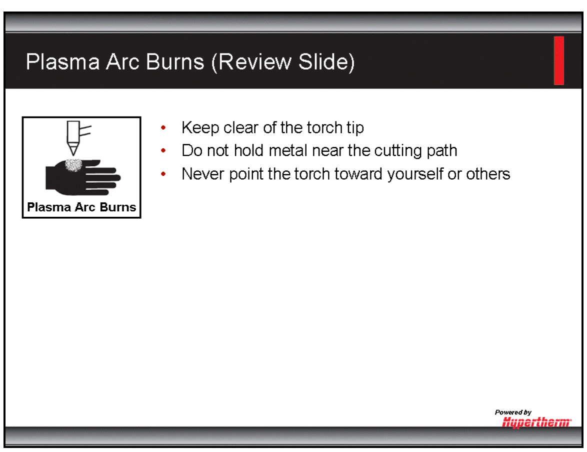


Slide 8: Toxic Fumes

The material being cut can be a source of toxic fumes or gases that deplete oxygen. Metals that may release toxic fumes include, but are not limited to, stainless steel, carbon steel, zinc (galvanized), and copper. Metal can also be coated with substances that can release toxic fumes; they may include, but are not limited to lead, cadmium, and beryllium.

To reduce the risk of exposure to fumes:

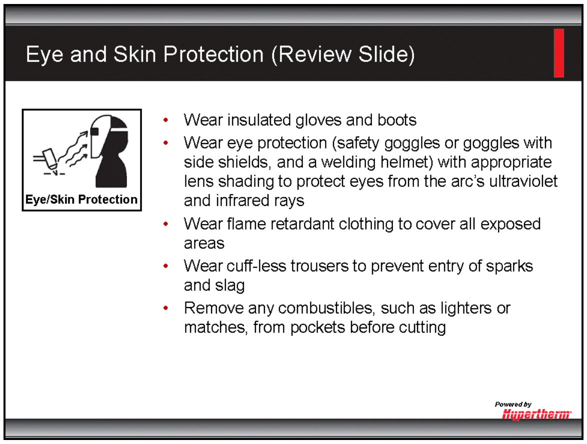
- Remove all coatings and solvents from the metal before cutting.
- Use local exhaust ventilation to remove fumes from the air.
- Wear an air-supplied respirator when cutting metal coated with, containing, or suspected to contain toxic elements.
- Assure that operators are qualified and trained.
- Never cut containers with potentially toxic materials inside, as this presents inhalation and explosion hazards; empty and properly clean the container first.
- Monitor or test the air quality at the site as needed.
- Consult with a local expert to implement a site plan to ensure safe air quality.



Slide 9: Plasma Arc Burns

The plasma arc forms immediately when the torch switch is activated and will cut quickly through gloves and skin.

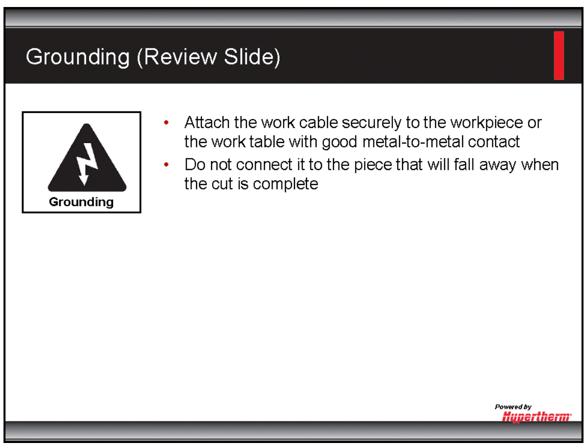
- Keep clear of the torch tip.
- Do not hold metal near the cutting path.
- Never point the torch toward yourself or others.



Slide 10: Eye and Skin Protection

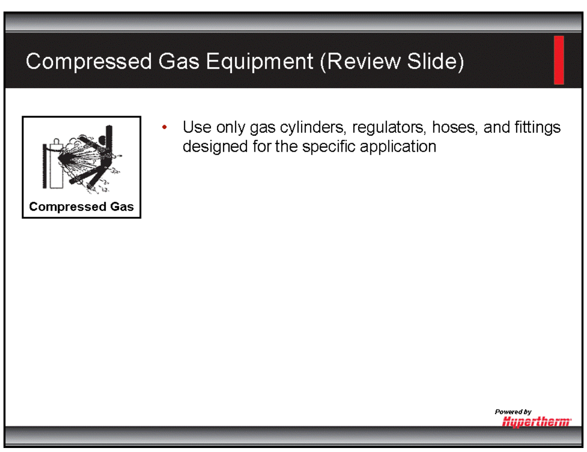
Plasma arc rays produce intense visible and invisible (ultraviolet and infrared) rays that can burn eyes and skin.

- Wear insulated gloves and boots.
- Wear eye protection (safety goggles or goggles with side shields, and a welding helmet) with appropriate lens shading to protect eyes from the arc's ultraviolet and infrared rays.
- Wear flame retardant clothing to cover all exposed areas.
- Wear cuff-less trousers to prevent entry of sparks and slag.
- Remove any combustibles, such as lighters or matches, from pockets before cutting.



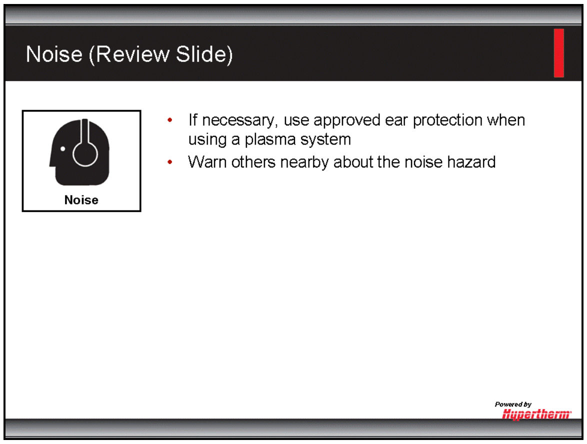
Slide 11: Grounding

- Attach the work cable securely to the workpiece or the work table with good metal-to-metal contact.
- Do not connect it to the piece that will fall away when the cut is complete.



Slide 12: Compressed Gas Equipment

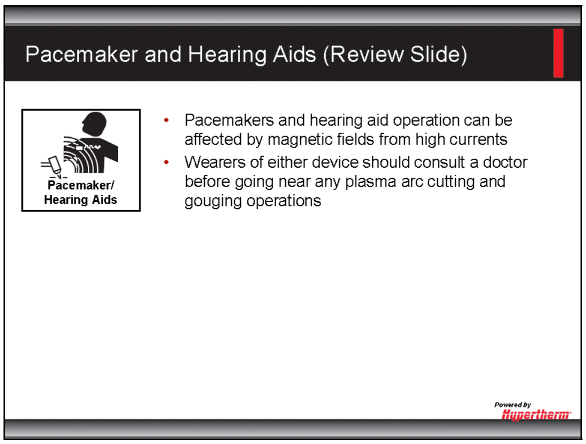
- Use only gas cylinders, regulators, hoses, and fittings designed for the specific application.



Slide 13: Noise

Prolonged exposure to high levels of noise can damage hearing.

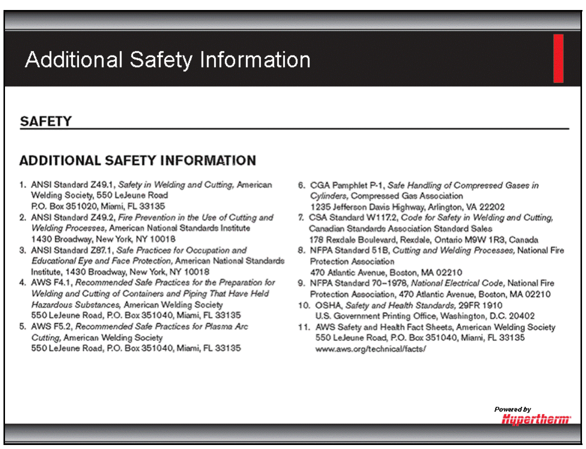
- If necessary, use approved ear protection when using a plasma system.
- Warn others nearby about the noise hazard.



Slide 14: Pacemaker and Hearing Aids

Pacemakers and hearing aid operation can be affected by magnetic fields from high currents.

- Wearers of either device should consult a doctor before going near any plasma arc cutting and gouging operations.


Additional Safety Information

SAFETY

ADDITIONAL SAFETY INFORMATION

1. ANSI Standard Z49.1, *Safety in Welding and Cutting*, American Welding Society, 550 LeJeune Road P.O. Box 351020, Miami, FL 33135
2. ANSI Standard Z49.2, *Fire Prevention in the Use of Cutting and Welding Processes*, American National Standards Institute 1430 Broadway, New York, NY 10018
3. ANSI Standard Z87.1, *Safe Practices for Occupation and Educational Eye and Face Protection*, American National Standards Institute, 1430 Broadway, New York, NY 10018
4. AWS F4.1, *Recommended Safe Practices for the Preparation for Welding and Cutting of Containers and Piping That Have Held Hazardous Substances*, American Welding Society 550 LeJeune Road, P.O. Box 351040, Miami, FL 33135
5. AWS F5.2, *Recommended Safe Practices for Plasma Arc Cutting*, American Welding Society 550 LeJeune Road, P.O. Box 351040, Miami, FL 33135
6. CGA Pamphlet P-1, *Safe Handling of Compressed Gases in Cylinders*, Compressed Gas Association 1235 Jefferson Davis Highway, Arlington, VA 22202
7. CSA Standard W117.2, *Code for Safety in Welding and Cutting*, Canadian Standards Association Standard Sales 178 Rexdale Boulevard, Rexdale, Ontario M9W 1R3, Canada
8. NFPA Standard 51B, *Cutting and Welding Processes*, National Fire Protection Association 470 Atlantic Avenue, Boston, MA 02210
9. NFPA Standard 70–1978, *National Electrical Code*, National Fire Protection Association, 470 Atlantic Avenue, Boston, MA 02210
10. OSHA, *Safety and Health Standards*, 29FR 1910 U.S. Government Printing Office, Washington, D.C. 20402
11. AWS Safety and Health Fact Sheets, American Welding Society 550 LeJeune Road, P.O. Box 351040, Miami, FL 33135 www.aws.org/technical/facts/

Powered by Hypertherm

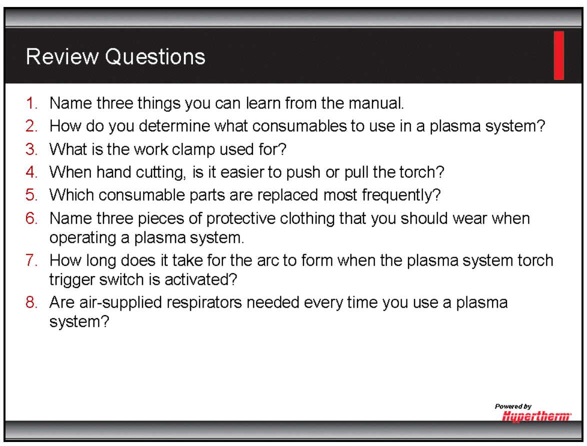
Slide 15: Additional Safety Information

- Additional safety information can be found in the resources shown on this slide.

Safety Equipment Activity

Slides 16 – 29: Safety Equipment Activity

Wrap-Up



Slide 30: Wrap-Up and Review Question Overview

Name: ______________________________

Date: ______________________________

Plasma Cutting Technology: Theory and Practice
Homework #4: Using a Plasma System Safely

1. Name three things you can learn from the manual.

   ____

   ____

   ____

2. How do you determine what consumables to use in a plasma system?

   ____

3. What is the work clamp used for?

   ____

   ____

4. When hand cutting, is it easier to push or pull the torch?

   ____

5. Which consumable parts should be replaced most frequently?

   ______________ ______________

6. Name three pieces of protective clothing that you should wear when operating a plasma system.

   ______________ ______________ ______________

7. How long does it take for the arc to form when the plasma system torch trigger switch is activated?

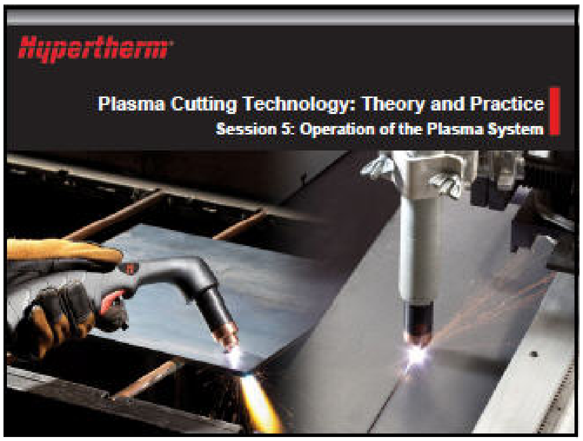
   ____

8. Are air-supplied respirators needed every time you use a plasma system?

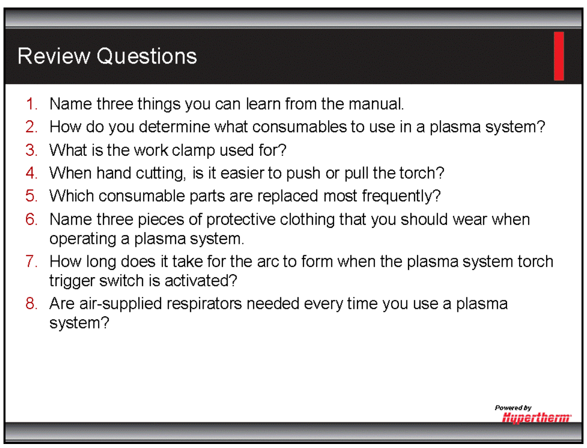
   ____

Session 5: Operation of the Plasma System

Introduction

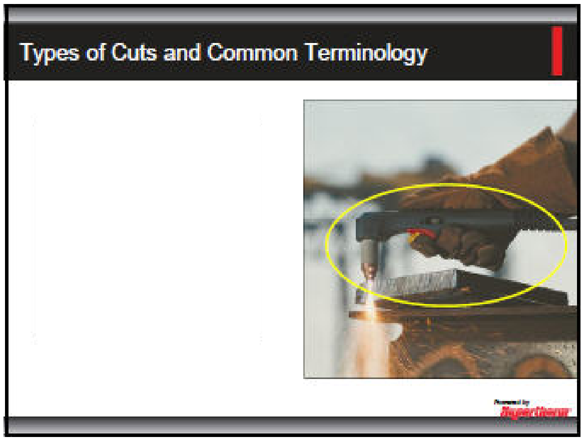


Slide 0: Title Slide

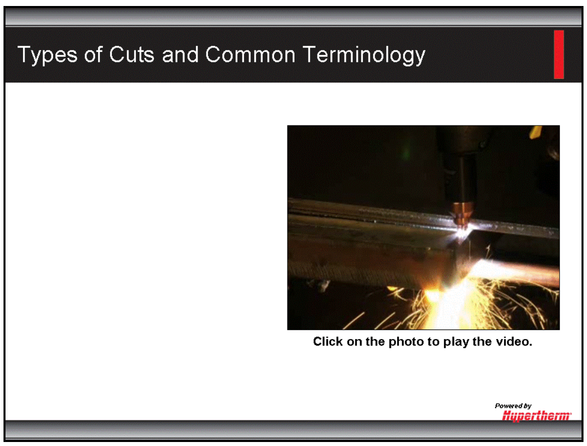


Slide 1: Review Questions

Common Terminology

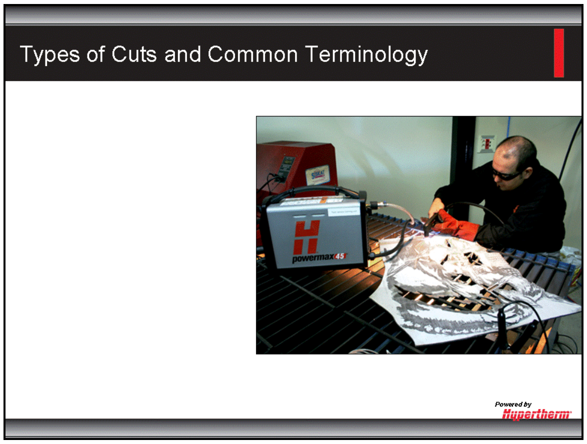


Slide 2: Common Terminology Review

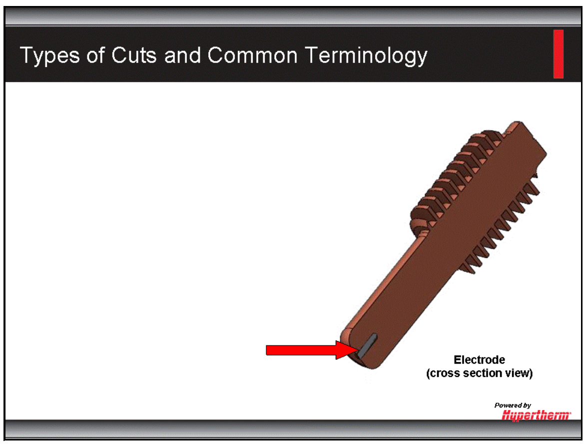


Slide 3: Common Terminology Review

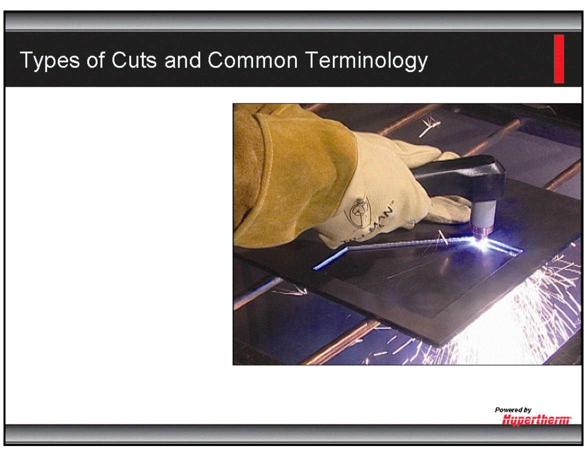
Slide 4: Common Terminology Review



Slide 5: Common Terminology Review

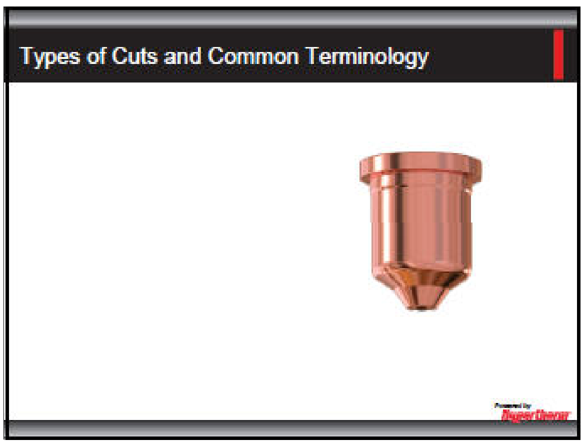


Slide 6: Common Terminology Review

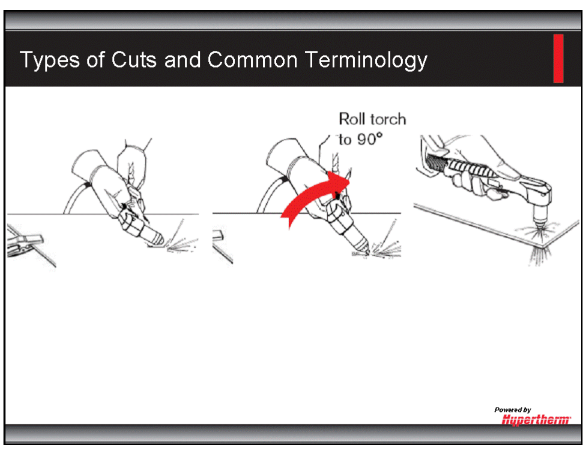


Slide 7: Common Terminology Review

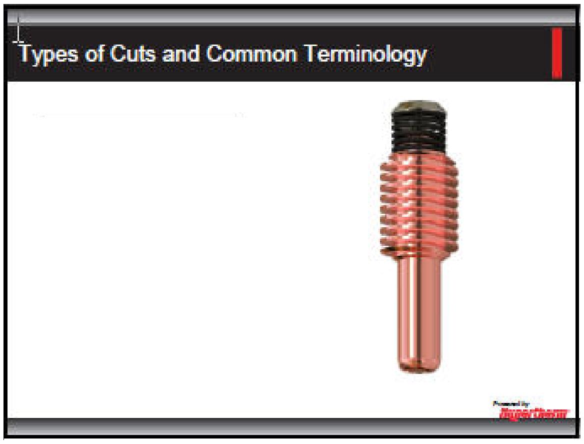
Slide 8: Common Terminology Review



Slide 9: Common Terminology Review

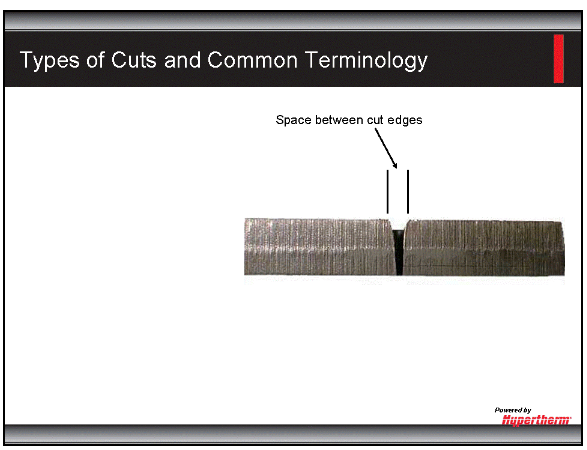


Slide 10: Common Terminology Review



Slide 11: Common Terminology Review

Slide 12: Common Terminology Review



Slide 13: Common Terminology Review

Machine Start-Up

Slide 14: Machine Start-Up

A summary of the information presented within the video is provided on the following pages.

Verify the power is disconnected and, if cord & plug type power source, verify the power plug is unplugged prior to Step 1.

Step 1: Check the proper installation of the torch consumables

- Unscrew the retaining cap to remove the parts within.
- Replace the parts by first inserting the nozzle, then the electrode, followed by the swirl ring.

  Screw the retaining cap on until finger tight; do not over-tighten as the consumables may become damaged.

Step 2: Connect the torch lead to the front of the power supply

Step 3: Connect the gas

- Pull back the quick release collar on the gas hose and insert on the quick disconnect fitting.
- The gas can be either bottled nitrogen, bottled air, or compressed air.
- Air should be filtered to remove all dirt, water, and oil because contaminants can damage the power supply, torch, and consumables.
- Minimum gas pressure: 80 psi or 5.5 bar.

  Maximum gas pressure: 100 psi or 6.9 bar.

Step 4: Attach the work clamp

- Check to see that the work lead is attached to the power supply. (Some systems do not have a quick disconnect on the work lead.) For the Powermax6, push the connector into the receptable and turn clockwise ¼ turn, making sure that the connector is fully seated against the stop to achieve an optimal electrical connection.
- Attach the work clamp securely to the work piece or the cutting table near the cut.
- Rust, paint, or coatings must be removed to be sure that the clamp has a good electrical contact.

  The clamp should never be attached to the portion of the metal that will fall away.

Step 5: Power on the system

- Plug the power cord into the proper receptacle.
- Power on the system.
- The power lamp on the front of the system will illuminate.

  For input voltage requirements, look at the data plate on the bottom or back of the power supply or in the operator manual.

Step 6: Set the mode switch

Set the switch to plate cutting. The position may vary. On the Powermax45, for example, it is the middle position. On the Powermax65, it is the second position.

Step 7: Check the gas pressure

- Systems such as the Powermax65 may have automatic gas adjustment. Unless there is a fault light illuminated and a gas pressure fault code on the LED screen, the gas pressure is correct. Other systems, like the Powermax45, may require that you adjust the pressure:
  - If the LED bar in the pressure gauge is green, the gas pressure is set correctly.
  - If the LED is yellow, the gas pressure needs adjustment.
  - To adjust the gas pressure, turn the amperage knob all of the way counter-clockwise to the “gas test” position.
  - Then, pull the regulator knob to unlock it.
  - Turn the knob until the green LED appears in the center of the pressure bar.
  - Then, push the regulator knob to lock it.

Step 8: Adjust the amperage

- Adjust the amperage knob to the top amperage setting for full cutting power (65 amps for the Powermax65).
- If cutting thinner metal, the amperage may be lowered for improved consumable life and cut quality.

Step 9: Operate the safety trigger

- Avoid unnecessary starts, because they reduce the nozzle and electrode life.

Performing an Edge Start and Drop Cut

- Hold the torch vertically (perpendicular to workpiece), just off the edge of the workpiece.
- The shield may be placed on the workpiece for ease of cutting.
- Flip the safety trigger forward and press the red torch trigger.
- The pilot arc transfers to the workpiece and becomes the cutting arc.
- Pause at the edge, allowing the arc to cut completely through the workpiece before proceeding with the cut.
- Pull torch steadily to cut.

  When nearing the end of the cut, roll your torch hand forward slightly, lifting your wrist. This will angle the torch into the direction of the cut, allowing the arc to completely sever the material.

Proper Travel Speed

- Maintaining proper travel speed is key to successful cutting.
- Watch the arc beneath the plate; sparks should lag 15° to 30° degrees behind the cut.
- If the sparks are vertical, then the speed is too slow.
- If the sparks are perpendicular to the cut or are spraying up from the workpiece, then the speed is too fast or the system does not have sufficient power. Lag lines on the finished cut edge should also be about 15° to 30°.

Template Cutting

- A plasma cutting guide, straight edge, or template can be used to guide the torch.

  The distance from the shield's center to the edge must be factored in when creating a template or placing the straight edge.

Bevel Cuts

If you are beveling using a plasma cutting guide or free hand, remember that the material thickness increases proportionally with the bevel angle.

Piercing

- The piercing capability of the system is roughly half of the maximum cut capacity
- Depending on the thickness of the metal being pierced and the system being used, there are two methods of piercing:
  - If piercing thin metal, hold the torch perpendicular to the workpiece and pull the trigger to transfer the arc.
  - If piercing thick metal, hold the torch at a 45° angle so that the nozzle is within 1/8" (3 mm) from the workpiece; pull the trigger to transfer the arc, then slowly rotate it to an upright position.
- In both methods, when sparks are exiting from the bottom of the workpiece the metal has been pierced and then cutting can begin.

  To prolong the life of the consumables, it is recommended that the second method be used to minimize damage to the consumables caused by molten metal blowback.

Cutting Expanded Metal

- To cut expanded metal (grating), or an application with interrupted cuts, set the mode switch to "Expanded Metal Cutting," which is the top position.
- This enables the system to automatically reinitiate the pilot arc without retriggering.
  To cut, simply follow the same procedures as outlined for plate cutting.

Gouging

- To gouge, first turn off the system, install the gouging consumables, then restart the system.
- Set the mode switch to gouging. On the Powermax45, this is the bottom position. On the Powermax65, it is the third position.
- Depending on the system you are using, you may need to adjust the gas pressure to get a wider, diffused arc for gouging. The Powermax65 does this for you. If you are using a Powermax45 or other non-autogas system:
  - Turn the current knob all of the way counter-clockwise to the "gas test" position.
  - Then pull the regulator knob to unlock it, turn the knob until the green LED appears in the center of the pressure bar, and push the knob back down to lock it.
- Adjust the amperage to full output for full gouging power.
- Hold the torch at approximately a 45° angle from the workpiece, with a small gap between the torch tip and the workpiece, then pull the trigger to transfer the arc.
- Maintain this angle and slowly move the torch along the workpiece to remove unwanted metal or weld.
- If a shallower gouge is desired, decrease the angle of the torch.
  For a deeper gouge, increase the angle of the torch or make additional passes.

System Optimization

- Cut quality and consumable life are two very important factors for operators.
- To ensure that the torch consumables last as long as they are designed to last and perform to manufacturer's specifications, follow the instructions in this video, refer to the supplied cut charts for proper setup, and follow proper maintenance procedures.
- A number of factors determine how long consumables last, including air quality, piercing technique, length of average cut, operator skill, material thickness, and material type.
- Reduced system performance and cut quality are often caused by poor air quality, so be sure to maintain clean, dry, oil-free air.

Accessories

Manufacturers offer a variety of accessories, including:

- Air filters
- Plasma cutting guides
- Leather torch sheathing
- System dust covers
- Face shields
- Gloves

Execute a Drop Cut

Purpose: *Build confidence with freehand plasma cutting by experimenting with technique, cut speed changes, torch angle changes, etc. Also, review and practice machine set-up and proper use of PPE.*

Time: *25 - 30 minutes*

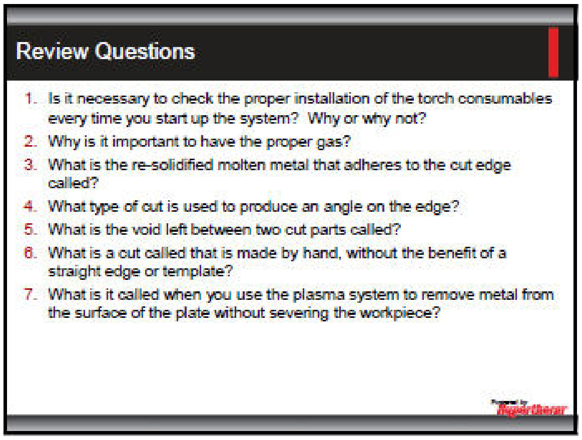
Materials:

1. Plasma system with all necessary hookups (air, power, ground).
2. Protective eye-wear for everyone in class.
3. At least one complete set of PPE (preferably 2+).
4. Copy of the appropriate "Quick Set-Up Guide."
5. Enough carbon steel for 50+ straight cuts [recommended: at least 3 feet (90 cm) x 1 foot (30 cm)].

Directions:

- Bring system to cutting area of the workshop.
- Mimic the **Machine Start-up** activity; students take turns using the "Quick Set-Up Guide" to prepare the plasma system for cutting.
- Review drop cut technique for group, demonstrating cut speed and torch angle WITHOUT actually cutting – leave the fun part for your class this time!
- First student puts on full PPE and checks that system is ready for cutting.
- Check that everyone has protective eyewear on before cutting begins. Remind class about safety as observers (distance from sparks, keep eye protection on for duration of cut, and so on.)
- Each student will get the opportunity to perform 2-3 drop cuts.
- Class observes the student cutting to provide constructive feedback.
- After each cut, stop and review technique with entire class.

Wrap-Up



Slide 15: Wrap-Up and Review Question Overview

Name: ____________________________

Date: ____________________________

Plasma Cutting Technology: Theory and Practice
Homework #5: Operation of the Plasma System

1. Is it necessary to check the proper installation of the torch consumables every time you start up the system? Why or why not?

____

____

____

2. Why is it important to have the proper gas pressure?

____

____

____

3. What is the re-solidified molten metal that adheres to the cut edge called?

____

4. What type of cut is used to produce an angle on the edge?

____

5. What is the void left between two cut parts called?

____

6. What is a cut called that is made by hand, without the benefit of a straight edge or template?

____

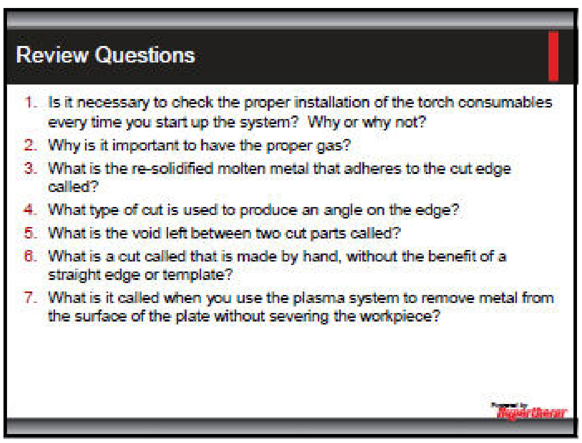
7. What is it called when you use the plasma system to remove metal from the surface of the plate without severing the workpiece?

____

Session 6: Evaluating Cut Quality and Troubleshooting

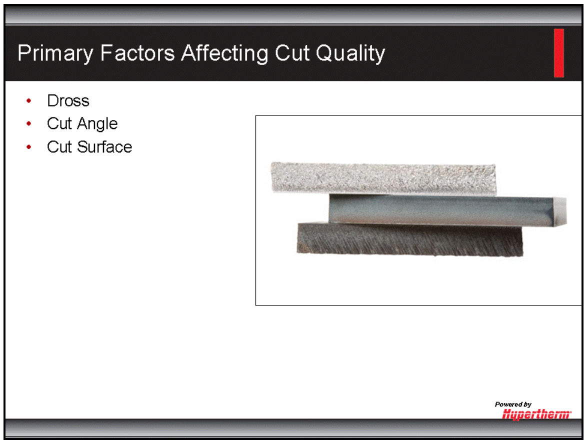
Introduction

Slide 0: Title Slide



Slide 1: Review Questions

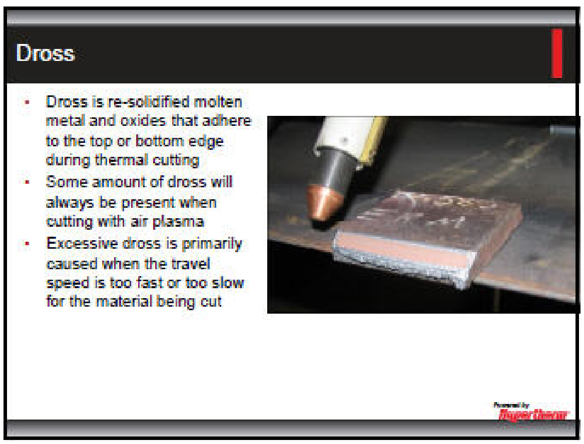
Primary Factors Affecting Cut Quality



Slide 2: Evaluating Cut Quality

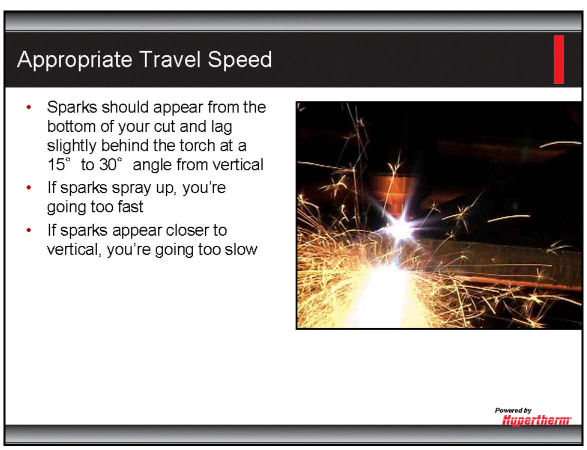
There are three primary factors to consider when assessing cut quality:

- Dross – the molten material that solidifies on the top or bottom of the work piece.
- Cut Angle – the degree of angularity of the cut edge.
- Cut Surface – the cut surface can be concave or convex, and may have varying surface finish (both in terms of straightness and texture); handheld plasma cutting typically produces a rougher cut surface than mechanized plasma.



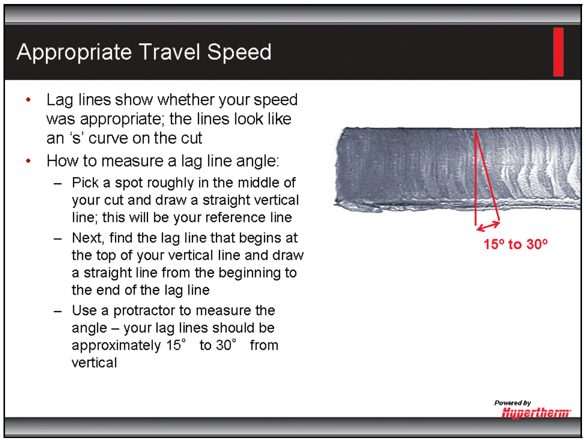
Slide 3: Dross

- Dross is re-solidified molten metal and oxides that adhere to the top or bottom edge during thermal cutting.
- Some amount of dross will always be present when cutting with air plasma.
- Excessive dross is primarily caused when the travel speed is too fast or too slow for the material being cut.



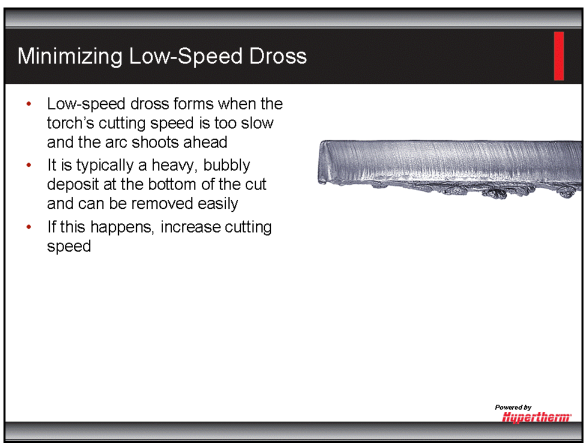
Slide 4: Appropriate Travel Speed

- When you are cutting at the correct speed, the sparks should appear from the bottom of your cut and lag slightly behind the torch at a 15° to 30° angle from vertical; this is hard to see for yourself – you may want to have someone watch and provide feedback as you cut.
- If sparks spray up, the torch is moving too fast; this is sometimes called a "rooster tail."
- If sparks appear closer to vertical from the bottom of the cut, the torch is moving too slow.



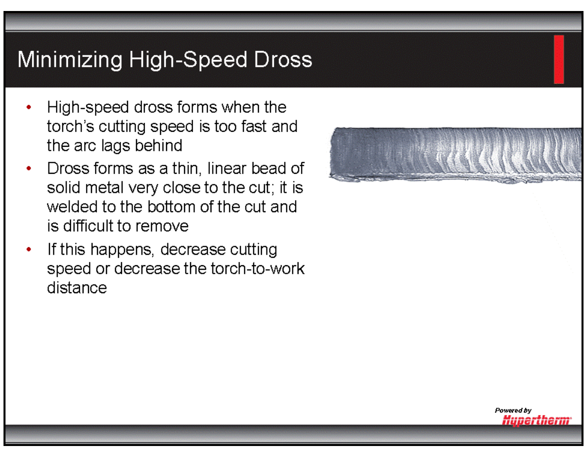
Slide 5: Appropriate Travel Speed (cont.)

- The lag lines on the edge of the cut show whether your speed was appropriate; the lines look like an 's' curve on the cut.
- How to measure a lag line angle:
  - Pick a spot roughly in the middle of your cut. Draw a straight vertical line. This will be your reference line.
  - Next, find the lag line that begins at the top of your vertical line. Draw a straight line from the beginning to the end of the lag line.
  - Use a protractor to measure the angle. Your lag lines should be approximately 15° to 30° from vertical.



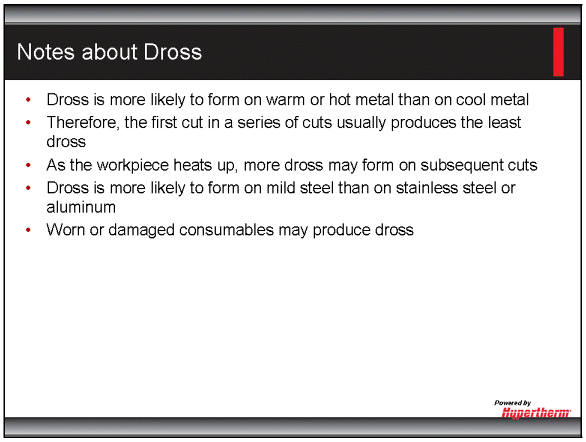
Slide 6: Minimizing Low-Speed Dross

- Low-speed dross forms when the torch's cutting speed is too slow and the arc shoots ahead.
- It is typically a heavy, bubbly deposit at the bottom of the cut and can be removed easily.
- If this happens, increase cutting speed.



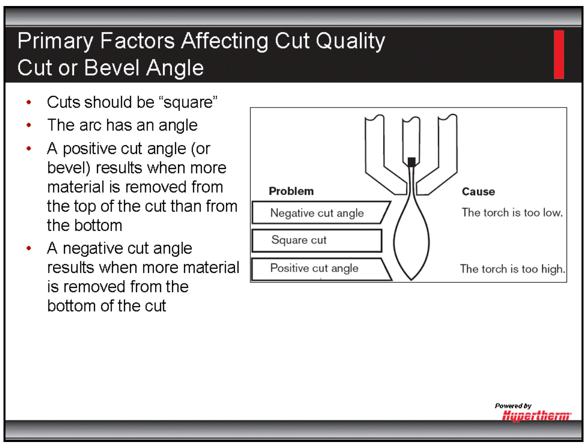
Slide 7: Minimizing High-Speed Dross

- High-speed dross forms when the torch's cutting speed is too fast and the arc lags behind.
- Dross forms as a thin, linear bead of solid metal very close to the cut; it is welded to the bottom of the cut and is difficult to remove.
- If this happens, decrease cutting speed or decrease the torch-to-work distance.



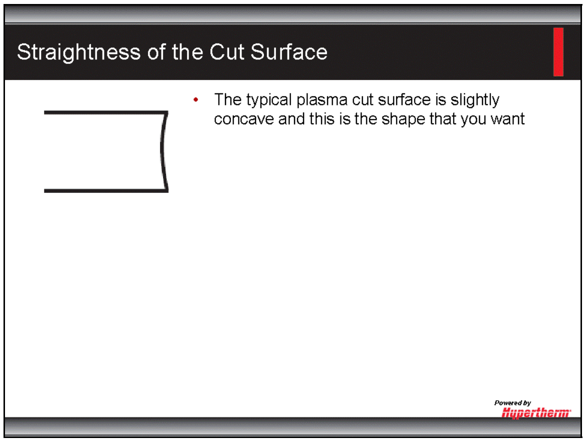
Slide 8: Notes about Dross

- Dross is more likely to form on warm or hot metal than on cool metal. Therefore, the first cut in a series of cuts usually produces the least dross. As the workpiece heats up, more dross may form on subsequent cuts.
- Dross is more likely to form on carbon steel than on stainless steel or aluminum.
- Worn or damaged consumables may produce dross.



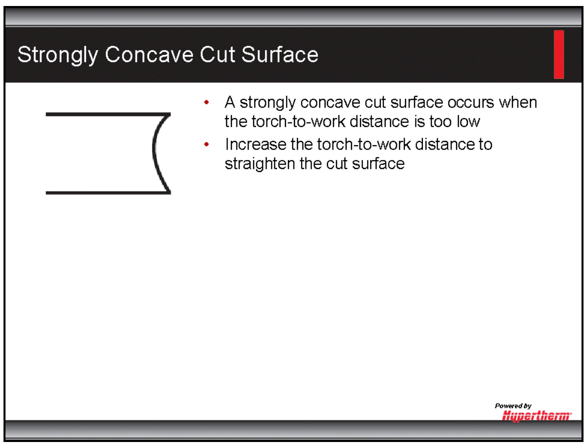
Slide 9: Cut or Bevel Angle

- You want the cuts that you make to be "square," which means that there is no bevel on the sides of the cut.
- We have mentioned several times that "the drag shield allows you to drag the torch along the surface of the workpiece, keeping the arc at the proper distance from the workpiece" – here is another illustration of how that works: it makes sure the arc shape that does the cutting is as close to square as possible.
- The arc itself has an angle as shown in the slide.
- A positive cut angle (or bevel) results when more material is removed from the top of the cut than from the bottom.
- A negative cut angle results when more material is removed from the bottom of the cut.
- Note that the highest quality cuts are always on the right with respect to the forward motion of the torch – this is because the arc swirls clockwise (when viewed from overhead), so it is actually hottest and the most dense where it exits the right cut edge.



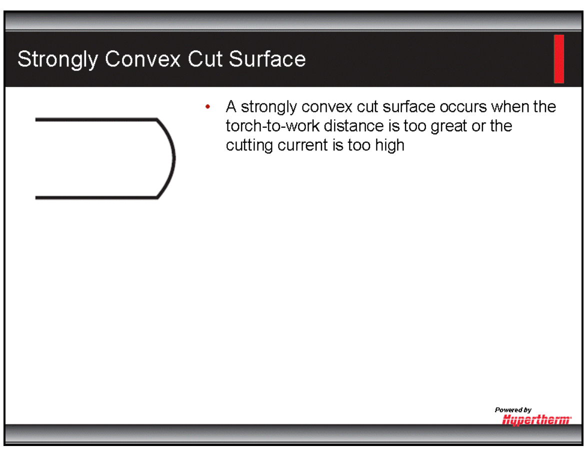
Slide 10: Straightness of the Cut Surface

- The typical plasma cut surface is slightly concave and this is the shape that you want.



Slide 11: Strongly Concave Cut Surface

- A strongly concave cut surface occurs when the torch-to-work distance is too low.
- Increase the torch-to-work distance to straighten the cut surface,



Slide 12: Strongly Convex Cut Surface

- A strongly convex cut surface occurs when the torch-to-work distance is too great or the cutting current is too high.

Evaluating Cut Quality Activity

Purpose: *Familiarize students with the measurement tools used to determine relative cut quality, as well as methods of optimization. Students will become more comfortable with self-assessment and will become familiar with how to recommend adjustments*

Time: *15 – 20 minutes*

Materials:

1. Cut Evaluation Worksheet – includes definitions of cut assessment terminology.
2. Student cuts from Session 5.

Directions:

- Gather the students' cuts from Session 5 and look at them as a group.
- Pick three or four cuts that show examples of variations such as high- or low-speed dross, good or bad cut angles, and/or convex or concave cut surfaces.
- Each student will have a cut evaluation worksheet to evaluate each cut based on what was learned within this lesson.
- When you are finished, discuss each cut as a group to provide feedback and reinforcement for student selections.

Name: ____________________

Date: ____________________

Cut: ____________________

Evaluating Cut Quality

1. Dross – the molten material that solidifies on the top or bottom of the work piece

Low Speed Dross **Dross Free** **High Speed Dross**

| | | | | | | | |

What would you do to improve the dross buildup on the work piece?

2. Cut Angle – the degree of angularity of the cut edge

Negative Cut Angle **Square Cut** **Positive Cut Angle**

| | | | | | | | |

What would you do to improve the cut angle?

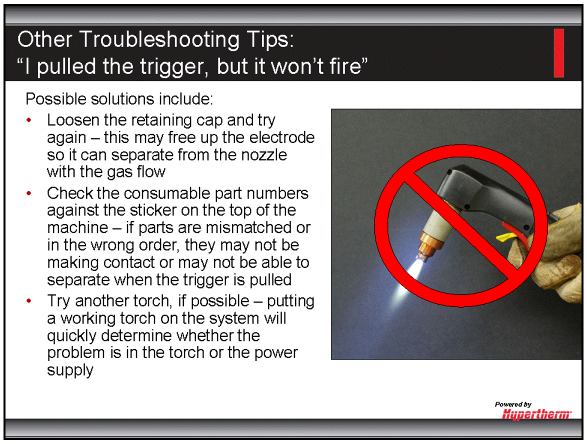
3. **Straightness of the Cut Surface – the cut surface can be concave or convex**

Concave **Straight** **Convex**

| | | | | | | | |

What would you do to improve the straightness of the cut surface?

Other Troubleshooting Tips

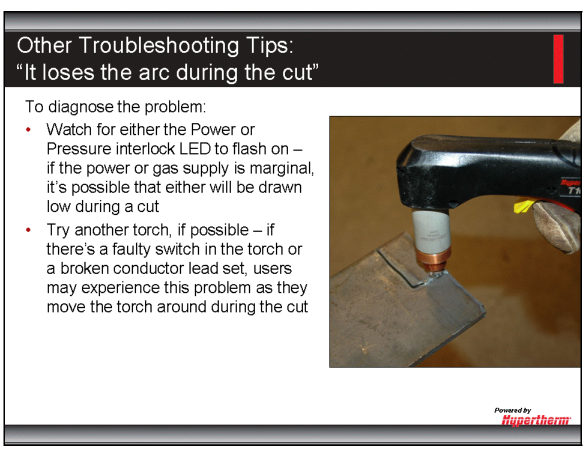


Slide 13: I pulled the trigger, but it won't fire

A plasma torch is designed to initiate an arc by running a current through the electrode and nozzle, which are touching when the torch is idle. When the trigger is pulled while current is flowing, the gas flow pushes the two pieces apart and produces the initial plasma. Without this separation or initial arc, a cutting arc will not form.

Possible solutions include:

- Loosen the retaining cap and try again – this may free up the electrode so it can separate from the nozzle with the gas flow.
- Check the consumable part numbers against the sticker on the top of the machine – if parts are mismatched or in the wrong order, they may not be making contact or may not be able to separate when the trigger is pulled.
- Try another torch, if possible – putting a working torch on the system will quickly determine whether the problem is in the torch or the power supply.

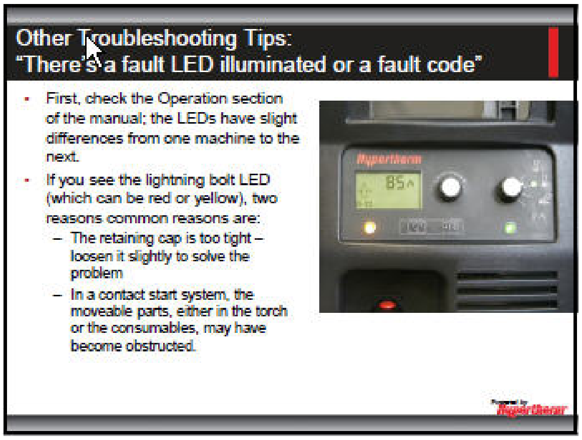


Slide 14: It loses the arc during the cut

If this happens only occasionally, it may be due to marginal power or a contaminated air supply. If it happens always or if substituting a working torch doesn't solve the problem, then it needs to go back to the manufacturer for repair.

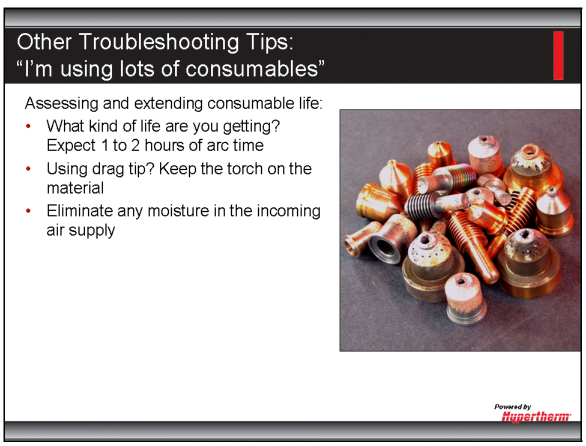
To diagnose the problem:

- Watch for a fault LED or fault code to flash on – if the power or gas supply is marginal, it's possible that either will be drawn low during a cut.
- Try another torch, if possible – if there's a faulty switch in the torch or a broken conductor in the lead set users may experience this problem as they move the torch around during the cut.



Slide 15: There's an interlock LED on

- First, check the Operation section of the manual; the LEDs have slight differences from one machine to the next. The manual should help solve the problem.
- If you see the lightning bolt LED (which can be red or yellow), two common reasons are:
    - The retaining cap is too tight – loosen it slightly to solve the problem.
    - The plunger has become fouled and isn't returning the electrode to its idle position (this may also cause pitting of the plunger).

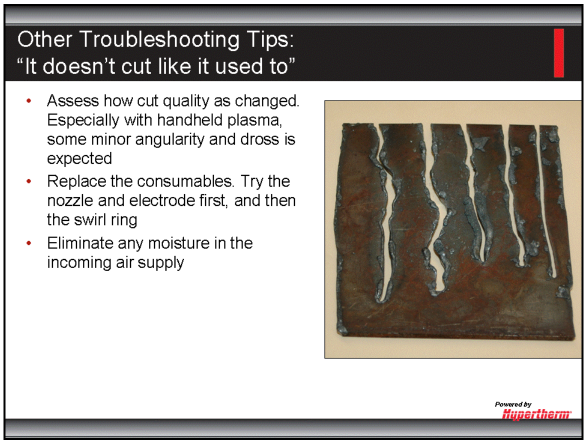


Slide 16: I'm using lots of consumables

Consumable life depends on many variables, including amperage (more amps = shorter consumable life), material thickness (greater thickness = shorter life), feed rate (faster cuts = shorter life), and piercing (edge-starting helps preserve consumables).

Some tips for assessing and extending the life of your consumables include:

- What kind of life are you getting? Expect 1 to 2 hours of arc time for manual cutting.
- Using drag tip? Keep the torch on the material.
- Eliminate any moisture in the incoming air supply.



Slide 17: It doesn’t cut like it used to

Cut quality is greatly influenced by the user’s technique. Therefore, the first step is to assess how the cut quality has changed (if at all).

Some tips for assessing and improving cut quality include:

- Assess how cut quality as changed. Especially with handheld plasma, some minor angularity and dross is expected.
- Replace the consumables. Try the nozzle and electrode first, and then the swirl ring.
- Eliminate any moisture in the incoming air supply.
- Change in the composition of the workpiece can affect cut quality.

Name: ______________________________

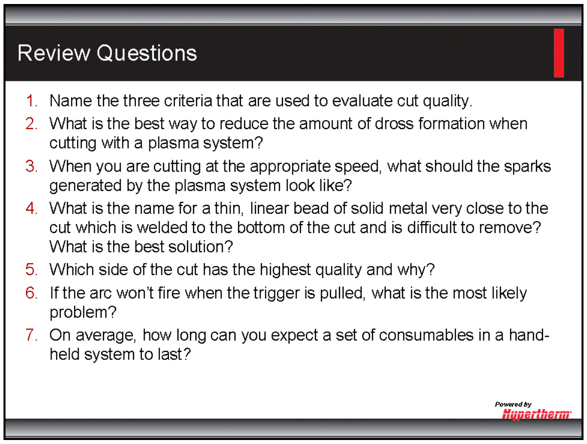
Date: ______________________________

Troubleshooting Activity

Match the problem with the most likely cause by writing the appropriate letter in the blanks on the left.

Problem	Most Likely Cause
_____ Convex Cut Surface	A. Cutting speed too fast
_____ Arc won't fire when the trigger is pulled	B. Torch-to-work distance is too low
_____ Thin, linear dross formation on the bottom of the cut	C. Cutting speed too slow
_____ Positive cut angle	D. Power or gas supply is marginal
_____ Negative cut angle	E. Mismatched consumables
_____ Heavy, bubbly dross deposit at bottom of the cut	F. Torch-to work distance is too high
_____ Torch loses the arc during cutting	G. If using a drag tip, keep the torch on the workplate
_____ Short consumable life	I. Torch-to-work distance is too great or cutting current is too high

Wrap-Up



Slide 18: Wrap-Up and Review Question Overview

Name: ______________________________

Date: ______________________________

Plasma Cutting Technology: Theory and Practice
Homework #6: Evaluating Cut Quality

1. Name the three criteria that are used to evaluate cut quality.

_________________________ _________________________ _________________________

2. What is the best way to reduce the amount of dross formation when cutting with a plasma system?

____

3. When you are cutting at the appropriate speed, what should the sparks generated by the plasma system look like?

____

4. What is the name for a thin, linear bead of solid metal very close to the cut which is welded to the bottom of the cut and is difficult to remove? What adjustment can be made to reduce this formation?

____

5. Which side of the cut has the highest quality and why?

____

____

6. If the arc won't fire when the trigger is pulled, what is the most likely problem?

____

7. On average, how long can you expect a set of consumables in a hand-held system to last?

____

Glossary

Bevel Cut	The cutting technique that uses a tilted torch to produce an angle on the edge of parts being cut.
Drop Cut	A cut that results in one section of the workpiece dropping away from the main piece.
Dross	Re-solidified molten metal and oxides adhering to the top or bottom edge of the workpiece during thermal cutting.
Electrode	The part of a consumable set that emits electrons in a steady stream to form the plasma arc.
Freehand Cut	Cuts made without the benefit of a straight edge or template.
Gouging	Removing metal from the surface of the plate without full penetration; used to remove old welds or prepare a surface for welding.
Guide Cut	Cuts made using a straight edge or template to guide the cut along a predefined path.
Hafnium	The metal used commonly as an electron emitter for air or oxygen plasma gases.
Hole Pierce	A method of starting a cut in which the arc plunges into and through the workpiece before cutting begins .
Kerf	The void left by the linear removal of material by any kind of cutting process; example: the width of the saw blade when cutting wood.
Nozzle	A consumable torch part containing a hole, or orifice, through which the arc passes.
Template Cut	Cuts made using a straight edge or template to guide the cut along a predefined path.
Torch	The part of the plasma system that is used to perform the actual cutting.