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1. Machine Description

This machine tool is a computer controlled water-jet or abrasive jet cutting machine. Water-jet machines are capable of cutting many types of materials including six-inch steel billet, foam, plastics, and stone to name a few. The work piece is placed on a stable surface, typically underwater. The high pressure stream is then used to abrade away excess material, leaving the finished product behind. A key advantage of water-jet cutting is that machining is not required after the cutting process. The desired shape is typically drawn in CAD and then converted to XY motions of the water-jet nozzle. There are a total of three axes of motion for the water-jet machine: two axes are slaved in a gantry configuration to perform the X motion and a Y axis is coordinated with the X axis motion to trace out the appropriate pattern.

The key to a water jet cutting machine is precise coordination of XY position along with control of speed and acceleration. XY position coordination is important to trace out the correct path, but speed and acceleration are also important considerations, as they affect the quality and width of the cut. Another important aspect is continuous motion. Once you begin motion along the tool path, it is usually undesirable to stop, because it can cause unintended wearing away of the work piece. For further information about the water-jet cutting process, please visit www.waterjets.org.

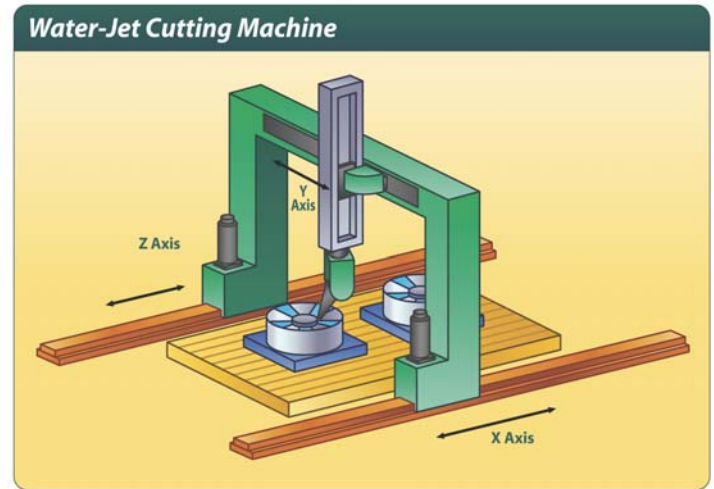


Figure 1.

2. Requirements

This section summarizes the requirements for the machine described above:

- (1) Three axes (XYZ) with forward and reverse limit switches on X and Y
- (2) XY coordinated to follow any two-dimensional path
- (3) Gearing X to Z to implement X axis gantry system
- (4) XY path specified by CAD
- (5) Graphical User Interface
 - User selects from a list of patterns
 - Selected pattern is displayed
 - Start button downloads path to controller and begins path

3. Components Selected

This section describes the Galil hardware and software products chosen to implement the machine's control system. Below is a complete bill of materials followed by a description of major components.

Table 1. Bill of Materials for Water Jet Control System

Part Number	Description	Unit Price (U.S.) Qty 1 / qty 100
DMC-2133	3-axis Ethernet, RS232 controller card with 96-pin DIN connector	\$1045/\$725
-DIN	DIN-rail mount option	\$100/\$50
-DC24	DC-to-DC converter option for 18V to 36V	\$100/\$70
AMP-20540	Amplifier Board with four 500 W PWM drives for brush or brushless servos	\$795/ \$495
BLM-N23-50-1000 or equivalent	NEMA 23 Brushless Servo Motor, 1000 ppr encoder X3	Consult mfg.
CPS-12-24 or equivalent	Power Supply 12A, 200 Watt	Consult mfg.
WSDK Servo Tuning Software	Servo Tuning and Analysis Software	\$195 (one time)
CADtoDMC	DXF to DMC translator	\$595 (one time)
ActiveX Tool Kit	Visual Basic/ ActiveX tools	\$595 (one time)
Visual Basic 6.0	Visual Basic development environment from Microsoft	Contact Microsoft

Controller: DMC-2133

The DMC-2133 motion controller allows the user to separate the controller from the PC and place it anywhere on the machine. The controller can communicate over 10Base-T Ethernet or RS-232.



Figure 2. DMC-2133 Motion Controller

Motor: BLM-N23-50-1000

For maintenance-free operation, we choose brushless motors. Galil's NEMA 23 #BLM-N23-50-1000 brushless motors, or equivalent, are appropriate because all axes require less than 0.3 Nm of continuous torque. Incremental encoders with 1000 cycles per revolution are installed on the motors resulting in 4000 quadrature counts per revolution. Hall sensors are not required on the motors as the incremental encoders provide commutation tracks for input to the amplifiers.

Amplifier: AMP-20540

To drive the three motors, we choose the very compact AMP-20540, which is a four-axis brushless amplifier (500 W per axis) that directly mounts to the top of the controller.



Figure 3. DMC-2133-DC24-DIN with attached AMP-20540

CADtoDMC

CADtoDMC is Galil software for Windows that takes an industry-standard .DXF CAD file and converts it into a Galil language .DMC file. This software can either be used as a stand alone program with its own GUI, or its functionality can be embedded into your own program (VB, C...) and GUI. The program simply prompts the user for a DXF file (which must conform to certain rules described in the CADtoDMC manual) and then displays the motion path when it is done converting. A .sen file will be generated in the same directory as the .dxf file. A .sen file is a Galil language file created by CADtoDMC which is sent to and executed by the controller line by line, whereas the .dmc file is made to be downloaded to the controller memory and then executed.

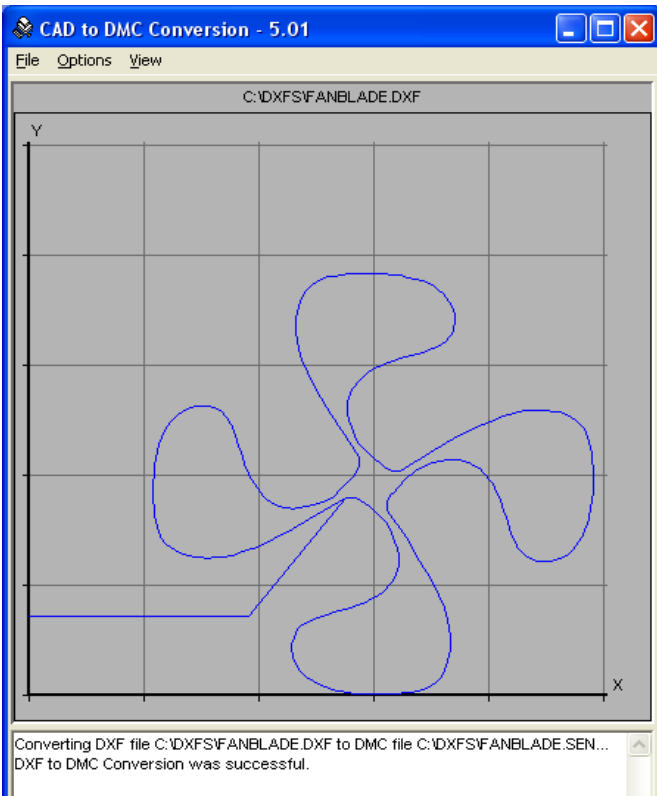


Figure 4. Galil's CADtoDMC software

ActiveX Toolkit

The ActiveX Toolkit provides ready-made GUI components that can be dragged and dropped into your application's GUI. The ActiveX Toolkit often greatly reduces software development when implementing a GUI that communicates with a Galil controller. For this application, we use the DMCMove object, which provides a picture of the pattern.

4. Implementation

This section details how the components selected above were used to implement the control system.

Vector (VM, VP)

The application requires that the XY axes be coordinated to follow a two-dimensional path. To meet this need, CADtoDMC uses the Galil controller's vector mode. Vector mode allows two axes to be linked together to perform linear and circular interpolation such that complex XY patterns can be executed. In vector mode, the X and Y axes are linked together and referred to as the S axis. Vector speeds anywhere along the path can be specified to tailor the motion profile (see VP command < and > operators in command reference). The simple example below draws a square of 1000 counts per side in vector mode:

```
VMXY      ;'specify xy axes for vector mode
VP1000,0  ;'specify points to travel through
VP1000,1000
VP0,1000
VP0,0
VE        ;'end the vector sequence
BGS      ;'begin motion
AMS      ;'wait until motion is complete
```

Gearing (GA, GR, GM)

The application requires that one of the axes be geared to the X axis for the gantry configuration. To meet this need, we establish a gearing relationship between the X and Z axes. The encoder used for feedback is the same for both devices so a 1:1 electronic gear ratio is set. Furthermore, gantry mode (GM) is used to more tightly couple the two axes (ST, AB, and the abort input do not break the gearing relationship—only GR0 stops the gearing).

```
GAZ=CX    ;'gear z axis to x axis commanded
          position for gantry operation
GRZ=1     ;'set gear ratio to 1:1
GMZ=1     ;'use gantry mode (ST doesn't
          break gearing)
```

Program Organization

The PC software is organized as a chain (figure 5). First, someone will create the desired part drawing in a CAD software package (such as AutoCAD). They then save the finished drawing as a DXF file. The DXF file is then processed through the CADtoDMC software, which creates a Galil-language .sen file. The machine user finally runs the Visual Basic application and selects the part from a list and hits the Run button to begin cutting the part.



Figure 5. Control Software Block Diagram

Graphical User Interface

When the Water Jet Visual Basic application is launched, it displays what controller it is connected to and presents the user with a list of part patterns. When the user clicks on a part pattern file (left), a two dimensional image of the pattern is displayed on the right (with the DMCMove ActiveX Toolkit object).

DMCMove is a component of the Galil ActiveX Toolkit that takes a Galil Language file as input (such as one generated by CADtoDMC) and produces an image of the path as output. This provides visual feedback so the

user is sure they have selected the correct pattern before they run it. When the user has selected the correct part pattern, they hit the Run button to initiate cutting.

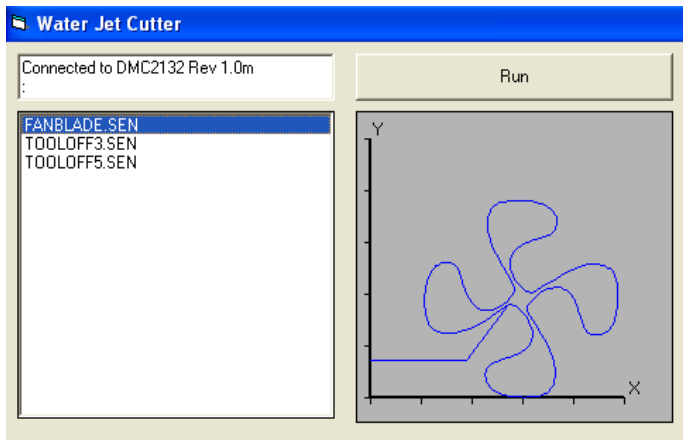


Figure 6. Water-Jet Graphical User Interface

DMC Code

The program below is downloaded to the controller and burned to the EEPROM with the BP command. This code runs once each the time the PC is booted to initiate the gearing and home the axes. The comments below explain the code in detail.

```
#AUTO
GAZ=CX      ;'gear Z axis to X axis for gantry
              operation
GRZ=1       ;'set gear ratio between the gantry axes
GMZ=1       ;'set gantry mode
'X and Y are homed to the reverse limit switch and
then the index pulse
JG*=-10000 ;'jog towards reverse limit switch
BGXY        ;'begin motion towards limit
AMXY        ;'wait until we hit the limit
JG*=500     ;'move slowly towards the index pulse
FIXY        ;'find index
BGXY        ;'begin motion towards index
AMXY        ;'wait until we hit the index. Position
              is set to 0.

EN
```

Visual Basic Code

This section shows the visual basic code for the application. It consists of only four routines that handle the following events:

- (1) Launching the program
- (2) Clicking on the file list
- (3) Clicking the Run button
- (4) Closing the program

The comments below explain the code in detail.

Figure 7. Visual Basic Code for Water-Jet GUI

```
Private Sub Form_Load()
    DMCSHELL1.DMCConnect = True
    DMCSHELL1.DMCCommand = Chr$(18) + Chr$(22)
    Text2.Text = "Connected to " + DMCSHELL1.DMCResponse
End Sub
'runs when program starts
'connect to the Galil controller
'send ctrl-R ctrl-V to query controller type
'display controller type

Private Sub File1_Click()
    DMCMove1.DMCFileName = File1.FileName
    DMCMove1.Open
End Sub
'file selection box event procedure
'inform DMCMove of .sen file to display
'display the file

Private Sub Command1_Click()
    If File1.FileName = "" Then
        MsgBox ("Please select a file")
    Else
        DMCSHELL1.DMCFileName = File1.FileName
        DMCSHELL1.DMCFileOperation = FileOperationDownload
        DMCSHELL1.DMCCommand = "XQ"
    End If
End Sub
'run button event procedure
'make sure the user has selected a file
'put up a message box if no file selected
'copy selected file name to ActiveX toolkit
'select file operation download to controller
'execute path

Private Sub Form_Unload(Cancel As Integer)
    DMCSHELL1.DMCCommand = "ST"
    DMCSHELL1.DMCConnect = False
End Sub
'runs when program ends
'stop axes and program running on controller
'terminate communication to controller
```