
Section 14: General Information

Helpful Formulas

Temperature
Degrees Fahrenheit (F) = $(9/5 \times \text{degrees C}) + 32$
Degrees Celsius (C) = $5/9 \times (\text{degrees F} - 32)$

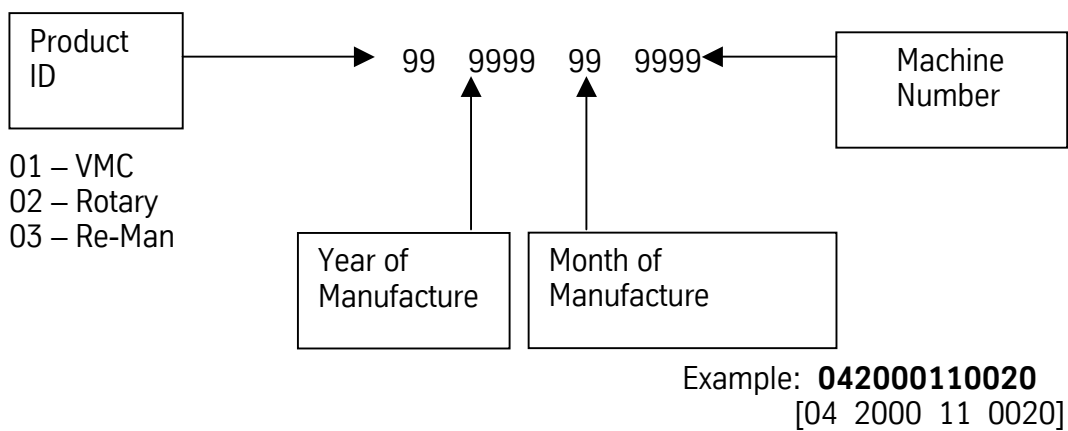
Conversion Factors
Inch (in) = millimeter x 0.03937
Inch (in) = centimeter x 0.3937
Millimeter (mm) = inch x 25.4
Centimeter (cm) = inch x 2.54
Liter = gallon (U.S.) x 3.7854
Gallon (U.S.) = liter x 0.2642
Bar = Pounds per Square Inch (psi) x 0.0689
Pounds per Square Inch (psi) = Bar x 14.5
Newton-metre (N/m) = pound/foot x 14.5939
Pound/foot = Newton-metre (N/m) x 0.0685
Newton-metre (N/m) = ounce-inch x 0.00706
Ounce-inch = newton-metre (N/m) x 0.1416

Electrical References
Formulas from Ohm's Law
Amperes (I) = Volts (E) / Resistance (R)
Resistance (R) = Volts (E) / Amperes (I)
Volts (E) = Amperes (I) x Resistance (R)
Single-Phase
Kilovolt-Amperes (KVA) = $(\text{Volts} \times \text{Amperes}) / 1000$
Three-Phase
Kilovolt-Amperes (KVA) = $(\text{Volts} \times \text{Amperes} \times 1.73) / 1000$

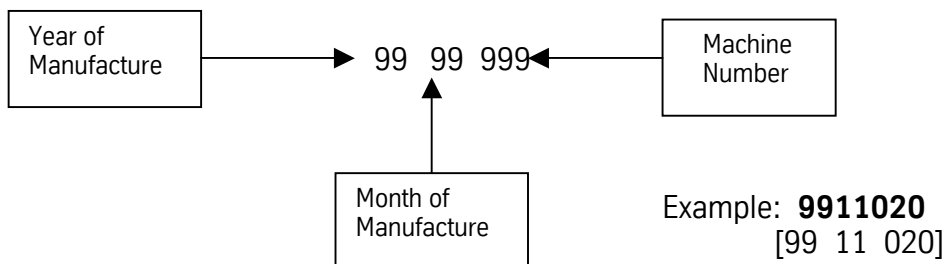
Expansion Coefficients
Formula
Expansion amount =
Coefficient x distance x degree of temperature change (Fahrenheit)
Coefficients
Steel = .00000633
Cast Iron = .00000655
Aluminum = .00001244

Fadal Machining Centers Serial Numbers

The new serial number scheme is as follows:



For reference the old serial number scheme:



**Communications
Troubleshooting**

For communication problems several factors must be examined. Review the environment, then check the file, the VMC, the cables, the computer, and finally the computer's communications software. Any one of these systems can propagate a communication problem.

Environment

In areas where lightning strikes are common, communications can be interrupted when or after lightning has struck a power line. The lightning may affect the memory of the CNC control, which would then have to be zeroed from the DI mode. It is suggested to call a service person or see the maintenance manual for this zeroing procedure.

- An RS-232 surge suppressor adds protection in this kind of environment.

File

- 1) Has the file ever successfully been transmitted to the VMC before? If the file has been transmitted before, has it recently been edited and has something been introduced into the file? Use an editor or word processor which will show hidden characters. If hidden characters are present in the file, remove them.
- 2) If the file has not been successfully transmitted, use an editor or word processor which will show hidden characters. If hidden characters are present in the file, remove them.
 - a. The only accepted characters allowed before the initial percent sign are DNC, DNCX, or TA,1. In addition, no O words are allowed in DNC mode.
Example:
DNC
%
 - b. A two-second dwell is required between the DNC command and the first percent symbol (%). If the software being used to transmit the program cannot support this dwell time, remove the DNC, DNCX, or TA,1 command from the file and type the command at the VMC before starting file transmission.
- 3) When a file is posted for a paper tape, or when a paper tape is read and placed on a disk, it may have leader characters before the initial percent sign — they need to be removed.
- 4) If some of the file can be transmitted, but some of it cannot, check for syntax errors.
 - a) Examine the area in the file for syntax errors and repair them. For example, double motion words or missing words are syntax errors.

Example:

X1.23 X4.5 — Double motion words
-Y2.3 — Incorrect placement of - (minus)
534 — No word at all

- Use the TA,1,1 command for program transmission so that the control will halt transmission and display the line where the syntax error occurs.
- 5) If a word processor or editor is used to write the program, it must be saved in a text only format. Some processors will add formatting characters to the file which will disallow communications.

VMC

- 1) Check to see if the grounding wires are properly attached.
 - a. The only proper and acceptable primary ground is a single continuous copper wire attached from the ground bus in the junction box of the VMC to the main power box of the building. A green sticker in the junction box further expounds the grounding requirement. Any other methods of grounding, such as grounding to the conduit, or to a ground rod, are not acceptable and will lead to communication problems. See the Pre-Installation section for grounding procedures.
 - b. Check to see if the screws attaching the ground wire to the VMC are tight at both ends.
 - c. The ground wire of the RS-232 DB25 plug on the inside of the CNC control cabinet must be attached from the RS-232 port to the inside of the CNC control cabinet. This wire is attached to pin #1 of the DB25 plug, and is used to shield the cable at the VMC end ONLY (see the FADAL VMC Users Manual for proper pin configuration).
 - If the paint has not been removed from this area, scrape the paint away and re-attach the wire.
- 2) Check the cable from the RS-232 port on the inside of the CNC control cabinet to the 1030 board.
 - a. Sometimes this cable will work itself out of the plug. Press the plug into the board to confirm a good connection.
 - b. Examine the cable for cuts or kinks and replace it if there is evidence of damage.
- 3) For VMCs with a phone modem, make sure that the DB25 plug on the inside of the CNC control cabinet is NOT plugged into the back of the

modem — if it is, it will interrupt normal communications through the RS-232 port.

- 4) Use the mirror plug to test the 1030 board. The mirror plug is stored in the bottom of the CNC control cabinet when the VMC is shipped. The plug is a DB25 plug with no wires coming from it. On the inside of the plug, pins 2 and 3 are crossed to complete the communications path. Plug the mirror plug into the RS-232 port on the outside of the back of the CNC control cabinet.
 - a. Use the diagnostics mode to complete the test.
 - 1) Move to the cold start position.
 - 2) From the command mode type DI then press ENTER.
 - 3) Type GO 3000 and press ENTER to enter the test menu.
 - 4) Press 4 to select the RS-232 (1030) test.
 - 5) Select a baud rate (generally the baud rate used in normal communications).
 - 6) Observe the screen.
 - Numbers next to the word TESTING should be changing constantly. If this occurs, the 1030 board has passed the test.
 - The numbers at the end of the other sentences should all be zero. If any numbers appear at the end of these sentences it is an indication that the 1030 board is faulty (assuming the cable was checked in step (2) above). **Note:** The 1030 is rarely faulty.
 - If the diagnostics test passes, then it is safe to conclude that the VMC is not at fault for a communication problem.
 - 7) Press the manual button to end the communication test.
 - 8) Power off the VMC, wait 10 seconds, then power on again.
- 5) Has the proper baud rate been selected at the VMC?
 - a. The CD,# command is used to select a baud rate. The MU command has a list of each baud in the menu, or see the users manual for the same list.
 - b. The SETP command, for the VMC parameters, can be used to select a baud rate as default. The CD,# command will temporarily override the selection in the SETP parameter page.

- Cables**
- 1) Verify that all connections between the communications cable and both the VMC and the computer are firmly seated, including surge suppressors, gender changers, and couplers. Pick up the cables and physically confirm that each connection is properly together.
 - Loose cable connections are one of the most common causes of communication problems.
 - 2) If a switch box is used, determine if the switch is in the proper position.
 - a. Examine the cable connections to see if they are in the correct ports.
 - b. Turn the switch handle back and forth a few times. Sometimes the contacts are corroded and turning the handle will temporarily correct the problem.
 - If turning the handle corrects the problem, it is suggested to clean the contacts or replace the switch box with a new one.
 - 3) If the cable is coiled because the cable is too long, it is suggested to get a shorter cable. The coiling may cause intermittent problems. The shorter the cable the less chance a parity error will occur.
 - 4) Check to see if the cable is draped over fluorescent lights or wrapped around or connected on the high-voltage line for the power to the VMC or other machines. This can cause RF noise and inductive voltages on the cable, and communications will be interrupted from time to time.
 - a. Welding machines and EDM machines close to the VMC or the cable will also cause communication problems. These machines also cause RF noise which interrupts communications.
 - 5) Open the DB25 plugs to see if the solder on the pins have been applied properly. Cold solder joints for these wires will need to be soldered again.
 - 6) Check to see if the wires are connected to the proper pins. See the Communication section of the User Manual for the proper pinout. Confirm that, with shielded cable, pin one is connected to the shield at the VMC side only. Pin one cannot be connected at the computer side.
 - 7) If straight cable is used then a null modem is required. A null modem cable can be purchased from the FADAL Parts Department (part # 4537), or from any computer store. A null modem is a short portion of cable or ribbon cable that has pins 2 and 3 crossed. The crossover and the proper jumpers on each end can be found in the Communication section of the User Manual.

- a. If a null modem is used that was supplied from FADAL, the switch must be in the outward position away from the cable.
- 8) Use the mirror plug test as described in step 4 of the VMC section above to test each section of cable from the VMC to the computer, replacing any section that fails.
- 9) What is the length of the cable?
 - a. The longer the cable the slower the baud rate must be. The faster baud rates may work for the longer cables, but the chance of losing information increases, the faster the baud. Try using a slower baud rate, and if this works better, this may be the best solution. However this also may indicate an IO port at the computer with low voltage. See the Computer and Computer IO Port section below.

Computer and Computer IO Port

- 1) Is the cable plugged into the proper port in the back of the computer?
 - a. Some ports are marked COM or SER — these are the proper ports.
 - b. If the ports are unmarked, a COM or serial port will be the male gender port (the port with the exposed pins — the female gender port will have sockets).
 - A gender changer plug may be needed if the gender on the cable will not plug into the proper COM or serial port.
- 2) Is the port active?
 - a. Is the cable on the inside of the computer cover attached to the port?
 - b. Check the voltage across pins 2 and 7 while transmitting a file (use a file large enough to allow time to check the voltage while the transmission is in progress). With the positive lead on pin 2 and the negative on pin 7, the voltage should range between 10 and 12 volts. Any voltage below 10 volts could result in interrupted communications.
 - A FLUKE meter (or equivalent) used to measure voltage must be set to AC to obtain a reading.
- 3) When the computer was set up, did any interrupts interfere with the communications port?
 - A qualified computer setup person will be able to confirm that the port is free of other interrupts.

- 4) If an IBM-compatible computer has a serial mouse, is the mouse plugged into the proper port?
 - a. Usually the serial mouse is used in COM1 or serial port one.
 - Move the mouse to COM1 and the VMC cable into COM2 and try to communicate again.
 - If the mouse is not to be used during the DNC process, remove the mouse software commands from the CONFIG.SYS and/or AUTOEXEC.BAT file(s), and then reboot the computer. (CAUTION: Only a person familiar with altering these files should perform this operation, as these files are necessary for startup of an IBM-compatible computer. Refer to the DOS manual for any questions regarding these files and how to properly modify them.)
- 5) Some screen saver software can interrupt communication, change the baud rate, or transmit an odd hidden character, when the screen saver starts to display. Remove or disable the screen saver software and try to communicate again.
- 6) The quality of the IO board must be considered. Multipurpose IO boards are usually not recommended. High quality boards dedicated to only IO functions are recommended. DigiBoard and Quad Tech are examples of companies which produce high quality IO boards. These boards are specific to the operating system used by the computer—one board is used for DOS, another for Windows, and another for micro channel (IBM PS/2). These boards usually test 12 volts across pins 2 and 7 at the computer, for the best quality transmission.
 - A FLUKE meter (or equivalent) used to measure voltage must be set to AC to obtain a reading.
- 7) If a network board is installed in the computer, the computer technician who installed the board must check for conflicting interrupts and IO addresses.
- 8) The FADAL Assist software has in its utility menu an RS-232 tester. Use the mirror plug in the port and follow the instructions on the screen for test number one.

Software

- 1) Check the communication parameters in the software.
 - a. TA, DNC, and PU (using Xon/Xoff)
 - Baud rate - This is variable and it must match the baud rate set at the VMC with the SETP command or with the CD,# command.

- Parity - E (Even)
 - Data Bits - 7 (Seven)
 - Stop Bits - 1 (One)
 - EOB (End Of Block) - CR,LF (ASCII 13,10)
 - Starting and ending character - % (ASCII 37)
 - Xon/Xoff (Software handshaking) disabled for TA
enabled for DNC and PU
 - Hardware handshaking - disabled
- b. DNCX (using XMODEM)
- Baud rate - This is variable and it must match the baud rate set at the VMC with the SETP command or with the CD,# command.
 - Parity - N (None)
 - Data Bits - 8 (Eight)
 - Stop Bits - 1 (One)
 - EOB (End Of Block) - CR,LF (ASCII 13,10)
 - Starting and ending character - % (ASCII 37)
 - Packet Data Bytes - 128
 - Hardware handshaking - disabled

For more information, see the file XMODEM.DOC on FADAL's Bulletin Board.

- 2) Use DOS to send a file, bypassing the communications software in the computer. If this works, the software is in doubt.
- a. From the DOS prompt type the following two DOS commands (shown in bold):

MODE COM2:2400,E,7,1 MODE port:baud,parity,data bits,
stop bits

MODE = DOS command (followed by a space)
port = COM2
: = : (the : is required DOS syntax)
baud = 2400
, = , (the , is required DOS syntax)
parity = Even
, = , (the , is required DOS syntax)
data bits = 7
, = , (the , is required DOS syntax)
stop bits = 1

TYPE **C:\CNCDATA\PN1234.NC>COM2** TYPE pathnamefilename>port

TYPE = DOS command (followed by a space)

pathname = C:\CNCDATA\ substitute the drive-and directories where
the file being sent to the VMC is stored.

filename = PN1234.NC substitute the name of the file sent to the VMC

> = > (the > is required DOS syntax to redirect file to COM2)

port = COM2

- Note: Before typing these two lines, the VMC should be in the TA,1 mode ready to receive the program at 2400 baud.
- Refer to the DOS manual for answers to additional questions about the DOS commands used here.

3) Running DOS-based software from Windows may not work for communications.

Thermal Expansion

Overview Thermal expansion is a natural occurrence in materials subject to heat, and there are several sources of heat in any machining operation. In addition, different materials react to heat at different rates, and different subsystems of the VMC react to specific machining operations to different degrees, further complicating matters. Finally, some machining practices designed to save time may actually aggravate the expansion problem. Fortunately, there are a number of ways in which the unwanted effects of thermal expansion can be reduced to acceptable tolerances.

Recognizing Thermal Expansion Changes in positioning can have many causes, and correctly identifying the cause is the key to solving the problem. Thermal expansion has a unique 'signature' which can aid in recognizing it as the culprit in a given situation. Position changes that are due to thermal expansion occur gradually over time, and continue to move in one general direction at a more or less constant rate. The best way to combat thermal expansion is to accept the inherent nature of it in a machining operation, and to take corrective measures, like those suggested in this document, ahead of time.

Accuracy and Repeatability It should be noted that when accuracy and repeatability are quoted for a machine, thermal expansion is not considered. These values are measured and recorded only when the machine and all of its components are thermally stable, usually by limiting test repetitions and time duration so that thermal

growth does not have a chance to come into play. For example, a typical industry test for linear repeatability involves only seven to ten moves away from and back to a position.

Expansion Coefficients

The rate of expansion of any particular material, due to temperature, can be measured. This rate of expansion is referred to as the expansion coefficient, and is measured per degree per inch. Using this rate of expansion, and the temperature of the material, the effects from heat can be predicted.

Material	Location / Usage	Expansion Coefficient
Steel	Ball Screws, Spindle, Fixtures, Sub Plates, Tooling, part stock	.00000633
Cast Iron	Head, Table, Column, Glass Scales, part stock	.00000655
Aluminium	Fixtures, Sub Plates, part stock	.00001244

Formula: coefficient * distance * degrees of temperature change = expansion amount

For example, if a nut is 23 inches from the motor mount and the temperature of the screw has changed 20 degrees, the screw length would have expanded .0029118 inches (.00000633*23*20 = .0029118).

Heat Sources

It comes as no surprise that the primary source of heat in machining is friction; however, some of the sources of friction, and all of the areas affected by a given friction source, may not be readily apparent. Additionally, the effects on the ambient temperature from various heat sources in the machine shop are often overlooked.

Friction

The most obvious heat source from friction is the cutting of material itself. Heat is transferred to the chips, which then can transfer their heat to the table. Heat is also transferred to the tool, and then to the spindle, and then to the head. Finally, heat is transferred to the part material itself, and from there to any fixture or sub plate holding the blank.

Movement of the table, and of the head, also generates heat from the friction. The ball screws turning produces friction between the nut and the screw, heating the screw and causing expansion, with the Y axis of the machine experiencing more thermal expansion than the X axis because the Y axis is moving more weight than the X axis. The movement of the table on the ways produces friction which can increase the expansion of the ball screws.

**Ambient
Temperature**

The general temperature of the shop environment will affect the machining process, but the most significant effect will be seen when temperature differences are created. Sunlight on a VMC will cause the side of the machine in the sun to expand at a different rate than the side in the shade. Radiant heat sources, such as ovens or hydraulic pumps, will heat the side of the VMC closest to them significantly more than the side furthest from the radiant heat source, causing uneven expansion. Cooling vents without diffusion gratings can blow cooler air onto one area of the VMC than another area, once again causing uneven expansion.

The goal is to surround everything with an even temperature. A shop at 90 degrees will experience more thermal expansion than a shop at 70 degrees, but a shop at 70 degrees with an air conditioning vent blowing directly on the VMC will experience more problems with uneven thermal expansion.

Machining Practices

There are a few machining practices that can aggravate thermal expansion, or its perceived effects, and deserve special mention. One is the use of rapid moves in a CNC program, which can vastly increase the friction, and therefore the thermal expansion, on the ball screws. The obvious drawback of reducing rapid moves is a slower production rate, however, this may be compensated for by increased accuracy and reduced scrap rates.

Another practice is using ceramic (or other) cutters without coolant and allowing the chips to sit on the table. The chips absorb the majority of the heat from the cutting process, and then transfer this heat to the table, causing the table to expand independently from any other part of the VMC.

A third practice is the use of cutting oil in place of water-soluble coolant. Although cutting oil does reduce friction at the surface of the cut, coolant does a much better job of carrying away the heat of the cut and minimizing the effects of thermal expansion resulting from that heat.

Yet another practice that deserves mentioning is machining parts at temperatures significantly different from those at which the parts are inspected. If the inherent expansion of the part material from the heat of the machining process is outside tolerance once the part has cooled to inspection temperatures, the problem can only be resolved by correcting for the heat generated during machining so as to keep the part material closer to inspection temperatures while the part is being machined. Along those same lines, it is important to use a gauge at approximately the same temperature as the temperature at which the gauge was calibrated.

Finally, the use of blanks for which the outside dimensions have been established prior to cutting is another practice which aggravates the effects of

thermal expansion. Since the blank is going to expand locally from the heat of cutting, the actual distance from edge to feature may change.

Non-Uniform Expansion

Material Differences

The differing rates of expansion by unlike materials further complicate the problems created by the heat generated in the machining process. This applies both to parts stock, like aluminum, and to fixtures and sub plates, often also made of a material like aluminum. Aluminum's coefficient of expansion is nearly twice that of steel or cast iron (the primary VMC materials), which means the aluminum will expand nearly twice as much as the ball screws, head, spindle, or table.

Fixtures / Sub Plates

Fixtures or sub plates of material other than the steel/cast iron of the VMC will cause the greatest problems in this area, unless the bottom of the fixture or sub plate is flat within .001° (please note that "parallel" is not the same as "flat", and flatness is the key in this area). For example, a sub plate made of aluminum has an expansion coefficient nearly double that of the table to which it is secured. If the flatness is not within .001", the heat of the machining process causing the sub plate to expand at twice the rate of the table will result in the sub plate actually bending the VMC's table. This will cause binding which will both affect position accuracy and cause undue wear on the mating surfaces under the table.

Machine Assemblies

Various assemblies of the VMC itself will be affected by different sources of heat in the machining process, and the effect of each assembly on positioning will vary accordingly.

For instance, the head will expand from two heat sources, the spindle heat and the ambient temperature. The effects of thermal expansion in the head will be seen in the directions of the Y axis and the Z axis, but not in the X axis, with the Y axis expanding away from the column (toward the operator) and the Z axis expanding down toward the table. Meanwhile, the Y axis itself will be expanding away from the column due to the expansion of the ball screw, which will compensate for the effect of the head's expansion in the same direction.

The ball screws will expand due to the friction of the nut. The effect will increase with the distance of the nut from the motor mounts (the effective length of the screw), and will be in the direction away from the motor mounts. Thermal growth of the ball screws is independent of growth in the head or the table.

The spindle experiences heat not only from the actual cutting, which is transferred through the tool, but also from its bearings. The spindle also

transfers most of this heat to the head, and the thermal growth is reflected in the head position, as mentioned above, and is independent of changes in the ball screws or table.

The table receives most of its heat secondhand, through the heat of the nut, the heat from the part (through the fixture or sub plate), and the heat carried by hot chips that lay on the table. Because of its large size, the table seems less affected by the heat of machining. It will expand, but it takes longer to heat or cool the entire table. In addition, the use of coolant tends to stabilize the temperature of the table at or close to coolant temperature.

A machining operation using rapid moves and low spindle speeds, with additional cooling at the part through FADAL's servo coolant subsystem, will generate much more thermal expansion in the ball screws, and hence the X axis and Y axis, than will be seen in the Z axis from the spindle or in the part material from the cutting. An operation using very high RPM spindle speeds with slower interpolated moves would experience more Z axis expansion, but would experience less expansion in the X axis and Y axis, and might actually experience less expansion in the part material because the high rate of chip removal carries much of the heat away from the part.

Each machining operation has a unique combination of factors that apply to predicting and managing the thermal expansion inherent in machining. Finding the right solution is a matter of combining various approaches, many of which are outlined in the pages that follow.

Solving the Thermal Expansion Problem

General Considerations

A simplified description of the thermal environment in machining would state that heat is generated through friction, and also input through ambient factors. That heat is transferred among the system components, and is either removed from the system through radiation, convection and evaporation, or absorbed by the components of the system (part, fixture, VMC).

In its simplest form, any solution designed to combat thermal expansion must reduce friction, reduce ambient influences, or increase heat removal through radiation, convection or evaporation. A complementary approach is to simply compensate for the changes brought on by thermal expansion. In a real life situation, a balance of approaches is required.

Ambient Sources

Sunlight Do not allow direct sunlight on the VMC. Window shades that diffuse sunlight can be acceptable, but any source of warmth that only heats one side of the VMC at a time will cause uneven warming and further complicate thermal considerations.

Cooling Systems Diffusion gratings on air conditioning vents can be used to prevent any air from directly blowing on the machine or part. Again, an unevenly heated part or machine will cause the heated, or cooled, portion of the part or machine to expand at rates different from the rest of the part or machine.

Radiant Heat If an operator can detect the radiant heat from other devices, a protective wall needs to be erected between the machine and the device radiating the heat. This type of heat source will cause the machine to heat up on one side and cause uneven expansion.

Binary Numbers

There are some mathematical concepts that will aide the troubleshooting process. The first discussion will be number systems.

Number Systems We all use the **Decimal System** or base 10, which is based on ten so when ten (10) counts are reached the next one causes a carry to the next column and each count in this column has a value of 10 times the previous column. Each place has a value ten times greater than the next place to the right. We use ten numerals (0 to 9) for this system.

1 0 0 1 0 0 1 1	<table style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 50%; padding-right: 10px;">One Hundred Twenty-eight</td> <td style="text-align: right;">128 X 1</td> </tr> <tr> <td style="padding-right: 10px;">Sixty-four</td> <td style="text-align: right;">64 X 0</td> </tr> <tr> <td style="padding-right: 10px;">Thirty-two</td> <td style="text-align: right;">32 X 0</td> </tr> <tr> <td style="padding-right: 10px;">Sixteen</td> <td style="text-align: right;">16 X 1</td> </tr> <tr> <td style="padding-right: 10px;">Eight</td> <td style="text-align: right;">8 X 0</td> </tr> <tr> <td style="padding-right: 10px;">Four</td> <td style="text-align: right;">4 X 0</td> </tr> <tr> <td style="padding-right: 10px;">Two</td> <td style="text-align: right;">2 X 1</td> </tr> <tr> <td style="padding-right: 10px;">One</td> <td style="text-align: right;">1 X 1</td> </tr> </table>	One Hundred Twenty-eight	128 X 1	Sixty-four	64 X 0	Thirty-two	32 X 0	Sixteen	16 X 1	Eight	8 X 0	Four	4 X 0	Two	2 X 1	One	1 X 1
One Hundred Twenty-eight	128 X 1																
Sixty-four	64 X 0																
Thirty-two	32 X 0																
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Eight	8 X 0																
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	<table style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 50%;"></td> <td style="text-align: right;">128</td> </tr> <tr> <td></td> <td style="text-align: right;">+ 16</td> </tr> <tr> <td></td> <td style="text-align: right;">+ 2</td> </tr> <tr> <td></td> <td style="text-align: right;">+ 1</td> </tr> <tr> <td style="text-align: right;">Decimal equivalent total</td> <td style="text-align: right; border-top: 1px solid black;">147</td> </tr> </table>		128		+ 16		+ 2		+ 1	Decimal equivalent total	147						
	128																
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	+ 2																
	+ 1																
Decimal equivalent total	147																

The other numbering systems work the same way; they just have different base numbers. By having a different base number, they also have a different number of numerals and the columns have different weights.

The **Binary System** or base two (2) is the basic system used by computers. Each place has a value twice as great as the next place to the right. Two numerals or digits (0 and 1) are used and they are referred to as “bits”.



To determine the decimal value, add the results of each column (column value multiplied by column weight).

Computers use binary number systems because they have two distinct states. The two states are variously called true and false, high and low, ON or OFF, or “1” and “0”. Two different voltage levels are used to represent the two states.

Binary Coded Decimal (BCD) is a numbering system used to represent a decimal number using a group of four (4) bits.

Hexadecimal (Hex) is a numbering system using base sixteen (16). This is a very common number system in computers. It uses sixteen (16) numerals 0 to F to represent the numbers.

The following are examples of the numbering system provided to show the differences.

Decimal	Binary	Binary Coded Decimal	Hexadecimal
0	0000 0000	0000 0000	0 0
1	0000 0001	0000 0001	0 1
2	0000 0010	0000 0010	0 2
3	0000 0011	0000 0011	0 3
4	0000 0100	0000 0100	0 4
5	0000 0101	0000 0101	0 5
6	0000 0110	0000 0110	0 6
7	0000 0111	0000 0111	0 7
8	0000 1000	0000 1000	0 8
9	0000 1001	0000 1001	0 9

10	0000 1010	0001 0000	0 A
11	0000 1011	0001 0001	0 B
12	0000 1100	0001 0010	0 C
13	0000 1101	0001 0011	0 D
14	0000 1110	0001 0100	0 E
15	0000 1111	0001 0101	0 F
16	0001 0000	0001 0110	1 0
17	0001 0001	0001 0111	1 1
18	0001 0010	0001 1000	1 2
19	0001 0011	0001 1001	1 3
20	0001 0100	0010 0000	1 4

Binary Number Groupings

Since the Binary Numbering System is the one used by computers there is a need to define the grouping of binary numbers.

Bit – one (1) binary location or digit.

Nibble – four (4) bits or binary locations.

Byte – eight (8) bits or binary locations.

Word – Sixteen (16) bits or binary locations.

Double Word – Thirty-two (32) bits or binary locations.

These grouping are used for many reasons. The most common are Data, Addressing and Status.

Reading Status Group

Reading a status in a computer can be very helpful for troubleshooting. Status is usually a byte or a word. The status is normally represented in hexadecimal. To demonstrate how a status byte is decoded, the command 1 byte in the diagnostics – display switches will be used. Each binary bit in the status byte will represent one relay in this case. Because Fadal uses negative logic, a value of zero (0) turns the relay on (activates it). B0 is the right-most bit. Each Hexadecimal digit is representing four (4) binary bits.

B0 = M68/M69

B1 = High range Idler

B2 = Unused

B3 = Drawbar / Geneva / Slide Enable

B4 = Drawbar

B5 = Air indexer

B6 = Coolant 1 On

B7 = Coolant 2 On

For example if the command 1 displayed “BD” then the binary equivalent would be “1 0 1 1 1 1 0 1”. To decode remember that “0” is On. In this example, B1 the high range idler would be On and Coolant 1 would be On.

VMC Maintenance

Cabinet Fans The fans in the cabinets must be functioning properly. The purpose of the fans in the cabinets is to cool the electronics and to move the heat out the vents. An excessive amount of heat in the cabinets, from clogged holes or nonfunctional fans, will transfer to the column and cause it to expand, as well as damaging the electronics. On a regular basis, remove and clean the vent hole grates, as the vents occasionally become clogged with dust or other particles, and inspect the fans to see that they are working.

Lubrication Lubrication is essential for the free motion of the table, saddle, and head, as well as for the nut on each ball screw. Each way must be lubricated, and the ball screws greased, to minimize both the wear on the machine and the excess heat generated by friction. The lubrication system must be inspected and serviced regularly. Inspect all of the ways to confirm that each way is getting lubricated. The lubrication system may need to be flushed by a qualified service person to remove any contaminants on the inside of the tubes and joints.

Machining Practices

Warm Up The first step in combating thermal expansion effects is also the simplest. Run the machine through a series of moves, at feeds and speeds equivalent to what will be encountered in the production run, long enough to reach an equilibrium; that is, where the amount of heat being generated is balanced by the amount of heat being removed (via convection, evaporation, or absorption through expansion of material). After that point is reached, the effect of thermal expansion in the VMC stabilizes, and the only corrections needed are for the expansion of the part material as each successive part feature is machined. Locate fixture offsets and establish tool length offsets after the machine has attained the optimum operating temperature. Avoid using moves or spindle speeds that exceed those used in the part program.

In addition to running a warm up routine at the beginning of the production shift, the same kind of routine can be run during breaks. This will maintain the VMC at operating temperature, especially the two subsystems that heat up or cool down the most (the spindle and the ball screws).

**Rough Cut / Cool
Down / Finish Cut**

A complement to the warm up of the VMC is the use of a rough cut to remove most of the material from the part. Although the part material heats up, the material can then be cooled to a stable temperature. Then, a series of finish cuts can complete the part in a short time, so that the material doesn't have time to expand beyond acceptable tolerance.

This process is also effective for inspecting parts. By cooling the part prior to the finish cuts, the temperatures at final cut and at inspection can be brought closer. In this situation, the target temperature should also be close to the temperature at which the gauge is calibrated.

**Monitoring Position
Changes**

The home position of the part will change as the temperature of the screws change. The operator can follow the home position changes throughout the production run and change the fixture home position and offsets accordingly.

Coolant

Using soluble and synthetic coolants that are mixed with water is the single most effective factor in removing the heat generated during cutting. Coolant is formulated specifically to absorb a great deal of heat within its molecular structure without having to radiate that heat onto the next material it contacts. Cutting oils are formulated for cutting, and lack the cooling quality of soluble and synthetic coolants mixed with water. Flood coolant is a better choice than either mist coolant or cutting oils because it benefits the cutting process in addition to providing heat removal.

The temperature of the coolant can be conditioned further through any of a few simple actions. Bags of ice floating in the coolant tank can be used to maintain the temperature. Pumping the coolant through a radiator, or through a copper coil in the coolant tank, or through a copper coil placed in a small refrigerator can all be used to condition the temperature of the coolant.

One side benefit of coolant is its cooling effect on the table as well as the part. As it is splashed around, the coolant's direct contact and its evaporation tends to keep the table at or near the temperature of the coolant, directly compensating for the effect of hot chips falling on the table. If the coolant temperature is being conditioned through some of the steps just mentioned, the thermal stability of the table benefits even more.

VMC Options

There are several options that can be added to a standard VMC to help manage the thermal expansion problems.

Probe A probe in the spindle can be used as a part of the program to discover what adjustments are required to compensate for thermal expansion. The probe can be used to pick up the new home position at the beginning of each program, or even at various times within the program. A probe can quantify the rate of expansion in the Z axis and a change can then be made to the tool table. The probe can also track the Y axis and X axis growth and, by using a macro, the fixture offsets can be altered without operator intervention. Because the amount of expansion differs depending on where the fixture is located on the table, each fixture should be relocated with the probe. A consideration when using a probe is that if a chip is in the spindle or on the probe's holder the probe will indicate an incorrect position.

Glass Scales Because they are independent from the ball screws, glass scales are more nearly accurate in positioning the table, but they are affected by thermal expansion themselves (generally from ambient temperature), and they cannot combat the expansion of the head. Keeping direct sunlight off of the scale covers and maintaining the ambient temperature to plus or minus one degree from a target temperature should allow glass scales to perform well. Still, other steps must be taken to minimize the effects of thermal expansion on the head, the spindle, and the part material itself. Glass scales are a good solution in a situation with multiple fixtures when a probe is not used.

Coolant Through Spindle FADAL's Coolant Through Spindle option is designed to work in conjunction with specific tooling (with a hole in the center) to allow coolant to be pumped deep into the part, where normally coolant does not reach. This significantly improves the rate at which heat is removed from the area of the cut, reducing the expansion of the part material. In addition, there is less heat to be transferred through the tool to the spindle and the head, so expansion of the spindle and the head is also significantly reduced, improving Z axis positioning and accuracy.

Cooled Ball Screws and Spindle The only effective way to greatly reduce the thermal expansion of the ball screws is to provide coolant through the center of the screws. Building on the Coolant Through Spindle concept, machines equipped with this feature pump a fluid through the screws and the spindle. A refrigeration unit, coupled to a thermostat, is used to control the temperature of the fluid, which consequently conditions the temperature of the screws and spindle as the fluid flows through them.

Conclusion Thermal expansion is a natural occurrence in any machining operation, and, when ignored, can significantly impact accuracy and positioning. By identifying and eliminating unwanted heat sources, by calculating or measuring expansion effects and altering positioning accordingly, by performing regular maintenance on the VMC, and by adopting the machining practices outlined above, the effects of thermal expansion can be reduced. For higher accuracy requirements, several options can be added to a standard VMC to further reduce expansion effects. Thermal expansion itself is unavoidable, but its undesirable effects can be eliminated.

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