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FSW NC Force Control Documentation

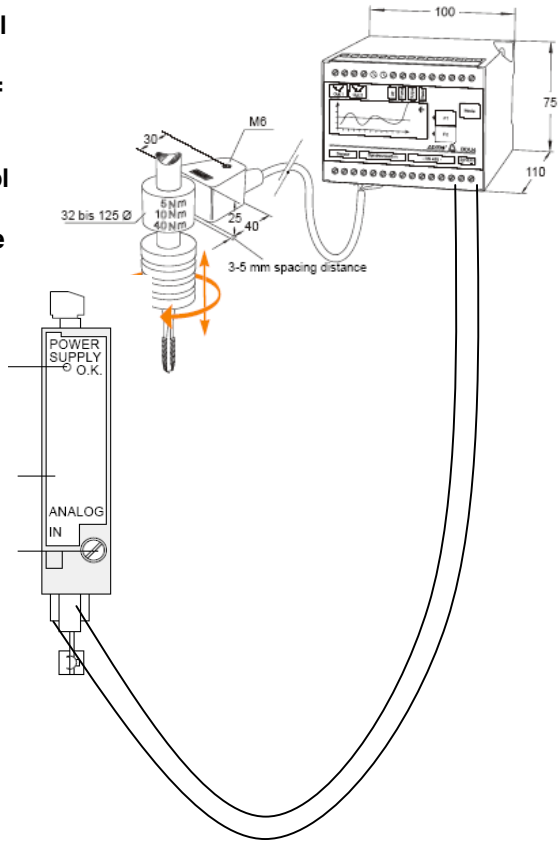
Contents

Introduction

Riftec GmBH in Hamburg Germany using a Tricept Robot for friction stir welding applications and have with this project realized a force control implementation, based on Artis DDU4 products and Siemens fast Analog Input options in the control Sinumerik 840D. By installing and connecting this hardware and also provide software solutions with functionality for force control loop, mainly implemented with use of 840D synchronous actions and PLC adaptions. The content of NC functions and the PLC interface functionality will be described in detail below. The cycles are not protected by any way and the source printouts and also the content of this documentation should be handled with care in respect of competition.

Force Sensor Setup

To read the force and/or the torque from Artis DDU4 tool into the NC, it is using a Sinumerik Analog FastIn DMP module. The DMP module is a fast type of update rate = 75 microseconds. There is no filters activated in the NC for this input, but in the cycles there is an average smoothing done and acts like a filter. At the Artis control side, the filter should be switched off. See setup instructions. Cable is connected to analog force/torque out at the controller to the dmp module. There is some alarm status and reset relay implemented in the plc and wired to the input/output at the controller. See plc doc.

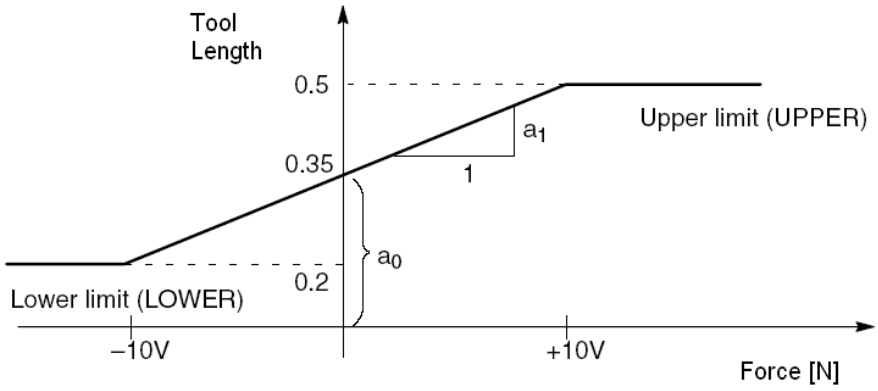


Analog Input & Conversion

The analog signal is converted to force by a calculation in the FSW_ANA_ON.SPF routine.
The force range at the sensor holder and the setting at the controller need to be adjusted and also a variable in the cycle routine must be set to the same level. Also the Volt output level +/- 10 V is adapted and can be changed if an output changing. See cycle code and doc below. Also the filter (time) is set by a variable in the cycle R7=100; Update rate in ms. This value will produce a smoothing input value which is averaged.

Force Calibration

The force relation with machine axis movement is done in a cycle FSW_FC_ON.SPF and are updated at lowest interpolator cycle time (Tricept 6 ms). Practically this update time is set to 200 ms to adapt to the FSW needs. The FSW tool pin is forced into the material with a tool oriented overlayed movement ($AA_OFF[axis]) and the distance per force unit are set by a polynom function with up to a three degree curve, but at this moment only the first degree is used (linear). The gradient of the curve is measured and calculated by running a cycle called FSW_FC_CAL.SPF. This cycle will force the tool into the material and measure the machine and material stiffness in relation to the movement to give an approximated start gradient a1. This could later be adjusted manually after needs. The input into this function is
The difference between actual force (FSW_ZForceActual) and the force setpoint (FSW_ZForceSetPoint). This means that the first coefficient a0 is set to zero. It is also limited by a min and max level variables and listed in the global user data list (MGUD) menu. The polynom curve looks like this:



All coefficients are present in the GUD menu and can be set manually. At a later test stage, there would be a possibility to set more degrees to get a larger reaction near the borders. See Sinumerik Programming Documentation "Polynomial function". The limits are also set by GUD variables, see cycle FSW_FC_ON.SPF list below.

Force Control

The correction of the tool is always done in the tool direction (calculated in x,y and z direction) of the machine base coordinate system (BCS). This coordinate system is the same as moving the Tricept in JOG mode following the machine table, i.e Z-tool direction perpendicular to the table surface. The movement is a so called overlayed or superimposed movement which means that there is no tool length compensation to do this, but a strict additive movement to the setpoint of the path. This movement can be seen in the real time variables $AA_OFF[X], $AA_OFF[Y] and $AA_OFF[Z]. The amount depends on the actual tool orientation in the BCS coordinate system. The overlayed compensation is configured to be an "integrated" movement which means that those values is adding at each interpolator time loop limited by the filter(gain) time set in FSW_FC_ON.SPF. It is also limited by the actual feedrate override at the machine panel with a linear functionality, so an override set at zero will stop the addition of movement. This total movement is also limited by a GUD variable based on the FSW_MaxToolLengthComp. This should be set to a value corresponding to an absolute additive movement where it can not destroy the machine by faulty operations and also a practical limit based on acceptable misalignments in frame deviations, i.e. path movement is not following the material to weld. This total overlayed movement can be watched in real-time variable $AA_OFF_VAL. If the limit is hit, the NC calls the retract function and moving away in tool direction with a distance of GUD variable FSW_ToolRetractDistance. The retract movement could also be called by pushing the "abort/retract" button on the machine panel. The overlayed movement can also be stopped by setting the GUD flag variable FSW_ZForceOn to off=0 or on=1. This is also a button.

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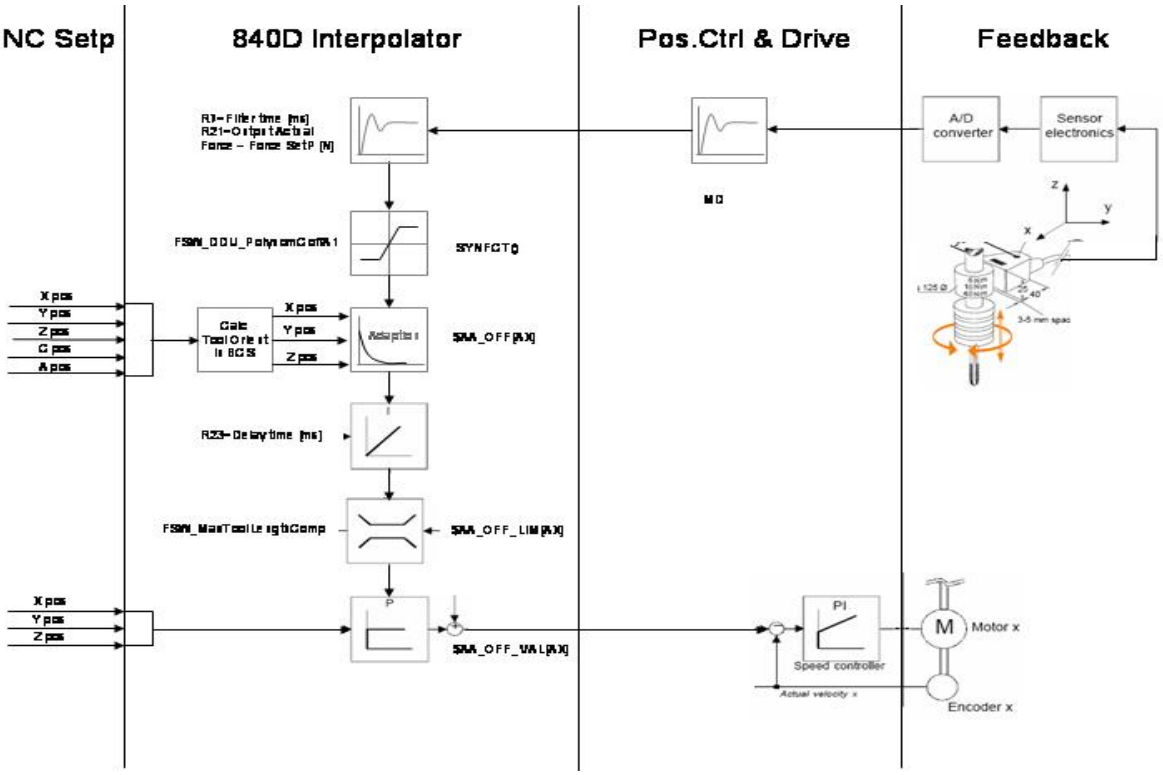
Force Control Scheme



NC Program Library Contents

Cycles in Work Piece Directory: FSW_CYCLES

o **FSW_ANA_ON.SPF**	**Switching on analog input with filter time.**
o **FSW_ANA_OFF.SPF**	**Switching off analog input.**
o **FSW_FC_CAL.MPF**	**Measurement and calculation of relation force – tool Distance movement.**
o **FSW_FC_ON.SPF**	**Switching on Force regulation.**
o **FSW_FC_OFF.SPF**	**Switching off force regulation.**
o **FSW_FC_POS.SPF**	**Position into material to a given force.**
o **FSW_EXAMPLE.MPF**	**Main nc-program example.**
o **GUDUPDATE.MPF**	**Nc-cycle running in channel two for updating global user data variables in real time.**
o **FSW_REC_ON.SPF**	**Switching on log-file recording.**
o **FSW_REC_OFF.SPF**	**Switching off log-file recording.**

Cycles in Standard SUBPROGRAM Directory:

o **FSW_RETRACT.SPF**	**Asup-cycle for retraction of tool in program or from Machine panel.**
o **EASYMASK.SPF**	**Asup-cycle for controlling machine panel buttons.**

Definition file in Standard Definition Directory:

- **MGUD.DEF** — **Definition file for global user data variables.**

Cycle in Channel 2:

- **GUDUPDATE.MPF** — **Update loop in channel 2. Should be selected as main prg. In auto mode at channel 2. Called by Channel 1. at nc-start. Setting GUD variables.**

NC Main Program Example

NC Program listing of an example nc program. Comments following each line with ";".

```
Traori          ; Tricept specific transformation activated
Dmson           ; Tricept specific tripod direct measuring system activated
Ffwon           ; feed forward on
T4 D1           ; tool number 4 activated, only a straight tool with length 1 = sensor length.
M216            ; activates length 1 in basic coordinate system
G56             ; activates working coordinate system 56, adapted to actual machine table.
;-------------------------
;Parameter setzen
TRANS X150 Y175 Z0          ; moving start point , i.e. translating working coordinates
G01 G90 F10000 X0 Y0 Z10 A2=0 B2=-3.5 C2=0          ; move tool to start pos.

M04 S1500                   ; starting spindle counter clockwise with 1500 rpm.

G01 Z1 F1000                ; move down to 1 mm above surface
FSW_ANA_ON                  ; analog input on
Z-2.2 F80                   ; move into material slow feedrate
G4 F0.5                     ; wait a half second
FSW_REC_ON                  ; start log of data
FSW_FC_ON                   ; force control on
X100 F300                   ; move robot 100 mm (welding)
```

```
FSW_FC_OFF              ; force control off
Z10 F1000               ; retracting to 10 mm above surface
FSW_REC_OFF             ; log data off, saving file
M5                      ; stopping spindle
Z100 F5000              ; move to safe height
;home_pos               ; goto home position
M30                     ; program end
```

NC Cycles

Variable explanation of cycles.

FSW_ANA_ON.SPF (Switching on analog input with filter time.)

```
FSW_DDU_ForceLimit=10   ; Select 2,5 or 10 kN. This should correspond to the Artis DDU4
                          controller setup.
R7=100                  ; Update rate in ms. This is the filter time and a possibility to smooth
                          the analog input by averaging. Keep filter off at controller and
                          smooth here instead.
R8=0                    ; Set VoltInput at zero. It is possible to set zero, i.e if the controller
                          could not be adjusted to zero output, put in the offset here.
R9 = 32752/10           ; [Volt input Convert] +/-10 Volt Analog Module. This correspond to
                          the Sinumerik Fast Analog Input module hardware which have a
                          11 bit resolution at +/- 10 volt span.
R10 = (FSW_DDU_ForceLimit*1000)/10.0   ; [N per Volt] conversion to Newton per volt input.
```

```
;R18        ;Last calculated analog average value
;R19        Force Input Value DDU4, averaged value and converted to force [N]. by
            scaling with R9 and R10. (Artis ouputs a minus value in tool direction, therefore a
            minus sign in R19 calculation.
;R20        Force value in, ActualForce - ForceSetPoint
;R21        Force value in, ActualForce - ForceSetPoint * ForceOverride
```

FSW_FC_CAL.MPF (Measurement and calculation of relation force – tool distance movement.)

```
FSW_ZForceSetPoint=3000         ;Set force level [N] to reach at force test. This
                                 should be equal or over an estimated force setpoint
                                 in the application tested for.
ForceLevelStart=200             ;Start point in force, i.e a smaller force at measuring
                                 start to avoid misreading values.
ForceSetPointDeltaMeas=500      ;Force span [N] of measurement. This span
                                 effecting the calculated slope average.
ToolDistanceMax=0.5             ;Limit for max correction value [mm]
ToolDistanceStep=0.001          ;Loop step distance when moving into material [mm]
StepFeedrate=500                ;Feedrate of infeed movement [mm/min]
```

FSW_FC_ON.SPF (Switching on Force regulation.)

R23=200	**;update rate time of force cycle [ms]. This value correspond to a "gain" factor in combination with polynomial coefficient FSW_DDU_PolynomCoffA1**
$SA_AA_OFF_LIMIT[Axis]	**; Limit the overlayed integrating movement as GUD FSW_MaxToolLengthComp)**
FSW_ZForceOn=1	**; Forcing the GUD variable to 1 at start.**
FSW_ToolRetractOn = 0	**;switch off Retract Flag.**
; $A_DBB[2]	**;Force Override factor , set by plc**
; R21	**; ForceInput = ForceActual ForceSetpoint*ForceOverride**
FSW_DDU_PolynomCoffA0=0	**; using setpointdiff R21 instead off offset, crossing at zero**

If limit $AA_OFF_LIMIT[X] is reached, nc calls Retract subprogram.

FSW_FC_POS.SPF (Position into material to a given force.)

ForceLevelStart=50	**;Smaller force at rest positioin[N]**
ForceSetPointStart=2500 ;[N]	**;When this force is reached, leave the subprogram and switch on force control.**
ToolPointLength=0.9 ;[mm]	**; The small tap length at the edge of the FSW pin to the shoulder.**
ToolDistanceMax	**; total length of tool including.**
ToolDistanceStep=0.01 ;[mm]	**; Step**
StepFeedrate=300	;Plunging Feedrate [mm/min]

Global User Data Variables and View

Global data def for friction steer welding application.

FSW_Feedrate	**;Actual Setpoint Feedrate [mm/min]**
FSW_RotDir	**;Spindle rotation CW=3/CCW=4**
FSW_Speed	**;Spindle speed[rpm]**
FSW_SpeedChange	**;Programmed Acceleration with NC command ACC[axis] [rpm/sec] (option)**
FSW_MaxToolLengthComp	**;Used to calculate max limits [mm]**
FSW_ZForceOn	**;Force Control Flag , OFF=0/ON=1**
FSW_ZForceActual	**;Actual Force input from analog in converted [N]**
FSW_ZForceSetPoint	**;Setpoint for force control [N]**
FSW_ZForceMax	**;Max force for control [N]**

FSW_ForceOverride **;Displaying the machine panel override status [%]**
FSW_ZForceMaxChangeRate **;Plus Limit for step force/overlay polynom [N/sec]**
FSW_ZForceMinChangeRate **;Minus Limit for step force/overlay polynom [N/sec]**
FSW_RecordStatus **;Possibility to switch on logfile , OFF=0/ON=1**
FSW_RecordSeqNumber **;Internal counter counting up at every call to RecOn.**
FSW_RecordFileName **;Path string for logfile name.**
FSW_DDU_ForceLimit **;Setable Force Limit [kN]**
FSW_DDU_ZeroForceAnaOut **;Zero point for Analog Input[V]**
FSW_DDU_MaxForceAnaOut **;Max limit for Analog Input[V]**
FSW_DDU_MinForceAnaOut **;Min limit for Analog Input[V]**
FSW_DDU_PolynomCoffA0 **;Defined offset in polynom**
FSW_DDU_PolynomCoffA1 **;Defined first degree (linear) in polynom**
FSW_DDU_PolynomCoffA2 **;Defined second degree in polynom**
FSW_DDU_PolynomCoffA3 ;;Defined third degree in polynom
FSW_SetForceCal **;Setpoint force calibrated**
FSW_WeightFactor **;ForceLimit calc**
FSW_ToolRetractOn **;OFF=0/ON=1**
FSW_ToolRetractDistance **;[mm]**
FSW_ToolRetractFeedrate **;[mm/min]**

PLC Implementations and interface signals

Some functions is set by the plc, so therefore this is a list of existing common nc interface variables are listed here:

$A_DBB[1] **;**
$A_DBB[2] **; Force Override Value at panel. Factor 0-120%**
$A_DBD[8] **; Used by EasyMask.spf (asup) selecting button row**
$A_DBD[12] **; Machine panel Push button code in EasyMask.spf (asup)**
$A_DBD[24] **; flag for FSW_ZForceOn**
$A_DBD[16] **;flag for calling asup retract in channel 1**
$A_DBD[16] ;flag for retracting tool routine.
$A_DBD[20] ;actual min force variable
$A_DBD[28] ;actual force value in synchronous action.
$A_DBD[32] ; Force Override Factor
$A_DBD[36] ; Force SetPoint
$A_DBW[4] ;Used by **EasyMask.spf (asup) selecting screen button**