Controls for Hall A SoLID Magnet Valves

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This note presents the control modes available for the Hall A SoLID magnet valves that regulate nitrogen and helium flow [1].

Figure 1 shows the operation modes available for the ten flow control valves—nine Joule Thompson Valves (JTV1–JTV7, JTV9, and JTV10) and the electric ball valve (EBV8).

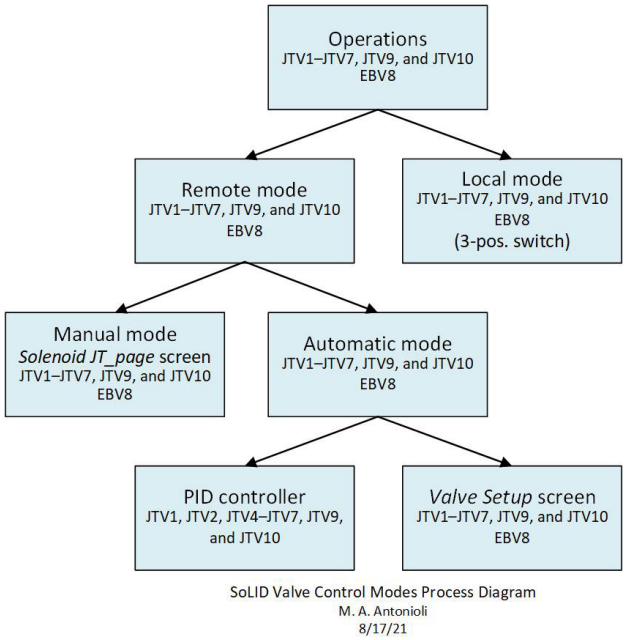

FIG. 1. Operation modes of the JTVs and the electric ball valve.

In the local mode, valves are controlled by 3-position switches installed on the valve panel [2]. In the remote mode, the PLC controls the valves in one of two modes: automatic—valve position determined by the PID controller or by set values on the *Valve Setup* screen [3]—or manual—valve position determined by set values entered on the *Solenoid JT_Page* screen [4].

In the automatic mode, an enhanced proportional integral derivative (PIDE) algorithm determines the control variable output (e.g. valve aperture) to maintain the process variable (e.g. liquid helium level inside the reservoir) at the set point. The algorithm uses the gain form equation [5], in which the gain factors are changed to keep the difference between the set point value and the process variable value, error value, close to zero. Table I provides information on parameters required by the PID controllers for the JTVs.

Some JTVs have two PID controllers, for example, JTV4, the liquid helium top fill valve. The first PID controller's process variable is the liquid helium level, and the second's is the 4 K liquid helium supply flow. For the first PID controller, the setpoint is the value for the liquid level inside the liquid helium reservoir and for the second, the setpoint is the value for the 4 K liquid helium flow supply limit. Figure 2 shows the process diagram for JTV4.

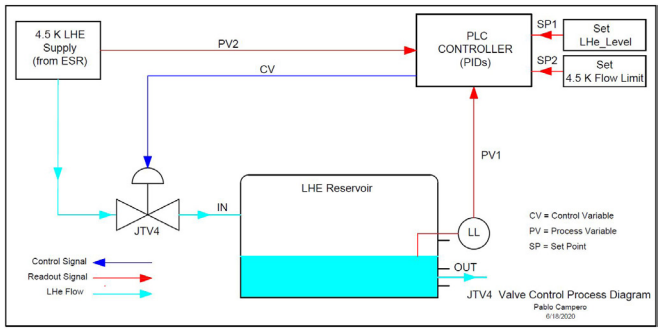

FIG. 2. JTV4 control process diagram.

Each PID controller generates output values for their control variables, which are used to generate a single value to set the aperture of JTV4. Figure 3 shows the flowchart for the PID control executed in the PLC code.

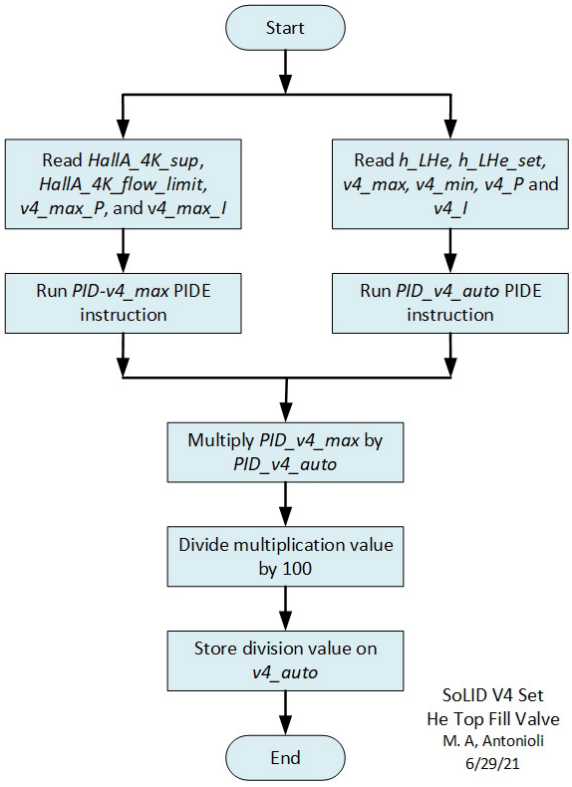

FIG. 3. JTV4 PID controls flowchart. PLC tag names used in the flowchart are described in Table I.

The PID control variable value is used if the valves are operated in the automatic mode *and* the cryogenic conditions are satisfied, otherwise, the valve's aperture is determined by the set value entered in the *Valve Setup* screen.

For example, in the automatic mode, JTV5, the liquid nitrogen top fill valve that regulates liquid nitrogen flow to the nitrogen reservoir in the CCR, accepts the control variable output value of the PID to set the valve aperture when the following conditions are satisfied: cooldown or standby operating mode is active, the read temperature in the magnet shield is below the set limit, the read liquid nitrogen level is greater than the set limit, and warmup or stop cooldown operating mode is not active. Otherwise, the valve uses the *Min. Setting* value from the *Valve Setup* screen.

All the JTVs and EBV8 may be controlled from the *Valve Setup* screen. For instance, EBV8, the helium warm return valve, is controlled by the set value for maximum pressure within the liquid helium reservoir and the set value for maximum temperature expected in the magnet. EBV8 is fully opened if the average temperature in the magnet is greater than the set value for maximum temperature or if the read pressure inside the liquid helium reservoir is greater than the set value for maximum pressure.

Code to perform PID controls over the JTVs was developed successfully [6].

[1] P. Campero, et al. *Controls and Monitoring Screens for the Cryo Control Reservoir's Instrumentation of the SoLID Solenoid*, DSG Note 2020-33.

[2] M. McMullen, et al. *Relay Board to Control JT Valve Motors of the SoLID Solenoid*, DSG Note 2020-29.

[3] P. Campero, et al. Controls and Monitoring Screens for the Cryo Control Reservoir Valves of Hall A's SoLID Solenoid, DSG Note 2021-09

[4] P. Campero, et al. Controls and Monitoring Screens for the Valves of SoLID Solenoid, DSG Note 2021-02

[5] Rockwell Automation, *Logix 5000 Advanced Process Control and Drives Instructions*, Publication 1756-RM006L-EN-P -, September 2020

[6] P. Campero, et al. Hall A SoLID Magnet PLC Control System, DSG Talk 2020-12, 2020

Valve name		Parameter	PLC tag name	Parameter description	Screen control
JTV1 Liquid Helium Cold Return*	PID controller	Process variable	P_He	pressure inside liquid helium reservoir	N/A
		Setpoint	P_He_set	set value for pressure inside liquid helium reservoir	yes
		Control variable	v1_auto	valve aperture in automatic mode	N/A
		k_i	v1_I	integral gain	yes
		k_p	v1_P	proportional gain	yes
		CV max	v1_max	maximum for control variable that corresponds to 100% CV	yes
		CV min	v1_min	minimum for control variable that corresponds to 0% CV	yes
JTV2 Cooldown Supply	PID controller 1	Process Variable	T_He_ Delta	delta of max and min temperatures in magnet	N/A
		Setpoint	T_HX_set_ CLEO	heat exchanger output temperature (varies for cooldown and warmup of magnet)	no
		Control variable	v2_auto	valve aperture in automatic mode (value stored in v2_auto after being combined with CV of PID controller 2)	N/A
		k_i	v2_pipe_I	integral gain	yes
		k_p	v2_pipe_P	proportional gain	yes
		CV max	v2_max	maximum for control variable that corresponds to 100% CV	yes
		CV min	v2_min	minimum for control variable that corresponds to 0% CV	yes
	PID controller 2	Process variable	Warm_Ret_ Flow	warm helium return flow to ESR	N/A
		Setpoint	Warm_Ret_ Flow_lim	set value for warm helum flow limit	no
		Control variable	v2_auto	maximum aperture in automatic mode (value stored in v2_auto after being combined with CV of PID controller 1)	N/A
		k_i	v2_max_I	integral gain	yes
		k_p	v2_max_P	proportional gain	yes
		CVH limit	V_max	CV high limit, used to set output alarm of PIDE instruction	no
JTV3 Liquid Nitrogen Bottom Fill	There is no PI control; valve is either fully open or closed				
JTV4 Liquid Helium Top Fill	PID controller 1	Process variable	h_LHe	liquid helium level in reservoir	N/A
		Setpoint	H_LHe_set	set value for liquid helium level	yes
		Control variable	v4_auto	valve aperture in automatic mode (value stored in v4_auto after being combined with CV of PID controller 2)	N/A
		k_i	v4_I	integral gain	yes
		k_p	v4_P	proportional gain	yes
		CV max	v4_max	maximum for control variable that corresponds to 100% CV	yes
		CV min	v4_min	minimum for control variable that corresponds to 0% CV	yes
	PID controller 2	Process variable	HallA_4K_ supply	liquid helium supply flow (from EPICS)	N/A
		Setpoint	Hall_A_4K_ flow_limit	set value for limit for liquid helium supply flow	yes
		Control variable	v4_auto	maximum aperture in automatic mode (value stored in v4_auto after being combined with CV of PID controller 1)	N/A
		k_i	v4_max_I	integral gain	yes
		k_p	v4_max_P	proportional gain	yes

JTV5 Liquid Nitrogen Top Fill	PID controller	Process variable	h_LN2	liquid nitrogen level in reservoir	N/A
		Setpoint	h_LN2_set	set value for liquid nitrogen level	yes
		Control variable	v5_auto	valve aperture in automatic mode	N/A
		k_i	v5_I	integral gain	yes
		k_p	v5_P	proportional gain	yes
		CV max	v5_max	maximum for control variable that corresponds to 100% CV	yes
		CV min	v5_min	minimum for control variable that corresponds to 0% CV	yes
JTV6 Liquid Helium Bottom	PID controller 1	Process variable	h_LHe	liquid helium level in reservoir	N/A
		Setpoint	S_level	set value for liquid helium level (lower than value used for JTV4)	no
		Control variable	v6_auto	valve aperture in automatic mode (value stored in v6_auto after being combined with CV of PID controller 2)	N/A
		k_i	v6_I	integral gain	yes
		k_p	v6_P	proportional gain	yes
		CV max	v6_max	maximum for control variable that corresponds to 100% CV	yes
		CV min	v6_min	minimum for control variable that corresponds to 0% CV	yes
	PID controller 2	Process variable	HallA_4K_ supply	liquid helium supply flow (from EPICS)	N/A
		Setpoint	Hall_A_4K_ flow_limit	set value for limit for liquid helium supply flow	yes
		Control variable	v6_auto	maximum valve aperture in automatic mode (value stored in v6_auto after being combined with CV of PID controller 1)	N/A
		k_i	v6_max_I	integral gain	yes
		k_p	v6_max_P	proportional gain	yes
JTV7 Liquid Helium Lead Pot Supply	PID controller 1	Process variable	P_He	pressure inside liquid helium reservoir	N/A
		Setpoint	P_He_set	set value for pressure inside liquid helium reservoir	yes (under JTV1 controls)
		Control variable	v7_auto	valve aperture in automatic mode (value stored in v7_auto after being combined with CV of PID controller 2)	N/A
		k_i	v7_auto1_I	integral gain	yes
		k_p	v7_auto1_P	proportional gain	yes
		CV max	v7_auto1_max	maximum for control variable that corresponds to 100% CV	yes
		CV min	v7_auto1_min	minimum for control variable that corresponds to 0% CV	yes
	PID controller 2	Process variable	P_He	pressure inside liquid helium reservoir	N/A
		Setpoint	P_He_set	set value for pressure inside liquid helium reservoir	yes
		Control variable	v7_auto	maximum valve aperture in automatic mode (value stored in v7_auto after being combined with CV of PID controller 1)	N/A
		k_i	v7_auto2_I	integral gain	yes
		k_p	v7_auto2_P	proportional gain	yes
		CV max	v7_auto2_max	maximum for control variable that corresponds to 100% CV	no
		CV min	v7_auto2_min	minimum for control variable that corresponds to 0% CV	no

JTV9 Heat Exchanger Liquid Nitrogen		Process variable	T_He_Delta	delta of max and min temperatures in magnet	N/A
	PID controller 1	Setpoint	T_HX_set_CLEO	heat exchanger output temperature (varies for cooldown and warmup of magnet)	no
		Control variable	V_HX_LN2_auto	valve aperture in automatic mode (value stored in V_HX_LN2_auto after being combined with CV of PID controller 2)	N/A
		k_i	JTV_HX_LN2_pipe_I	integral gain	yes
		k_p	JTV_HX_LN2_pipe_P	proportional gain	yes
		CV max	JTV_HX_LN2_max	maximum for control variable that corresponds to 100% CV	yes
		CV min	JTV_HX_LN2_min	minimum for control variable that corresponds to 0% CV	yes
	PID controller 2	Process variable	Warm_Ret_Flow	warm helium return flow to ESR	N/A
		Setpoint	Warm_Ret_Flow_lim	set value for warm helium flow limit	no
		Control variable	V_HX_LN2_auto	maximum valve aperture in automatic mode (value stored in V_HX_LN2_auto after being combined with CV of PID controller 1)	N/A
		k_i	JTV_HX_LN2__max_I	integral gain	yes
		k_p	JTV_HX_LN2__max_P	proportional gain	yes
		CVH limit	V_max	CV high limit, used to set output alarm of PIDE instruction	no
JTV10 Heat Exchanger Gas Helium	PID controller 1	Process variable	T_He_ Delta	delta of max and min temperatures in magnet	N/A
		Setpoint	T_HX_set_CLEO	heat exchanger output temperature (varies for cooldown and warmup of magnet)	no
		Control variable	V_HX_GHe_auto	valve aperture in automatic mode (value stored in V_HX_GHe_auto after being combined with CV of PID controller 2)	N/A
		k_i	JTV_HX__GHE_pipe_I	integral gain	yes
		k_p	JTV_HX_HX_GHE_pipe_P	proportional gain	yes
		CV max	JTV_HX_GHE_max	maximum for control variable that corresponds to 100% CV	yes
		CV min	JTV_HX_GHE_min	minimum for control variable that corresponds to 0% CV	yes
	PID controller 2	Process variable	Warm_Ret_Flow	warm helium return flow to ESR	N/A
		Setpoint	Warm_Ret_Flow_lim	set value for warm helium flow limit	no
		Control variable	V_HX_GHe_auto	maximum valve aperture in automatic mode (value stored in V_HX_GHe_auto after being combined with CV of PID controller 1)	N/A
		k_i	JTV_HXGHE_ _max_I	integral gain	yes
		k_p	JTV_HX_GHE__ max_P	proportional gain	yes
		CVH Limit	V_max	CV high limit, used to set output alarm of PIDE instruction	no

TABLE I. Parameters of JTVs.
*JTV1 is closed if the read position for EBV8 is greater than the setpoint, which can be entered on the *Valve Setup* HMI screen.