OPERATIONAL CHARACTERIZATION OF PRESSURE REGULATING VALVES

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ABSTRACT: In center pivot irrigation, pressure regulating valves (PRV) are usually installed upstream the emitters to set their inlet pressure and thus to compensate pressure variations along the lateral line due to pressure losses and terrain slope. PRVs are used to avoid significant variations in emitters' discharge, consequently assuring proper irrigation uniformity. The regulated pressure of PRVs is slightly influenced by its inlet pressure as well as the flow rate through it. The purpose of this work was to evaluate operational characteristics of pressure regulating valves (PRV) following requirements stated by ISO 10522 (1993). We carried out tests to evaluate regulation uniformity, regulation curve and regulated pressure as function of flow rate and inlet pressure. The following three models of PRVs were evaluated: 10 PSI, 15 PSI and 20 PSI. For each model, three samples were tested under increasing and decreasing conditions of inlet pressure, within the range of 50 and 800 kPa, with increments of 50 kPa. In addition, flow rates were tested within the range of 0 and 4 m^3 h^{-1}. From the gathered data, models to predict outlet pressure as a function of inlet pressure and flow rate were fitted.

KEYWORDS: laboratory tests, center pivot, irrigation

CARACTERIZAÇÃO OPERACIONAL DE VÁLVULAS REGULADORAS DE PRESSÃO

RESUMO: No sistema de irrigação por pivô central, válvulas reguladoras de pressão (VRPs) são geralmente instaladas anteriormente à entrada de água para os aspersores de uma tal maneira que a pressão de entrada seja regulada, compensando variações ao longo da linha do pivô devido à perdas de pressão (na forma de perda de carga) e declividades do terreno. As VRPs são utilizadas para evitar variações significativas na descarga dos aspersores, consequentemente garantindo uma uniformidade de aplicação adequada. A pressão regulada das VRPs é ligeiramente influenciada pela sua pressão de entrada assim como a vazão atravessando a

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válvula. O objetivo deste trabalho foi avaliar características operacionais de VRPs seguindo o indicado na norma ISO 10522:1993. Foram feitos ensaios para avaliar a uniformidade de regulação, a curva de regulação e a pressão regulada em função da vazão de entrada e pressão na entrada. Os três modelos de válvulas seguintes foram avaliados: 10 PSI, 15 PSI e 20 PSI. Para cada modelo, três amostras foram testadas em condições crescentes e decrescentes de pressão, na faixa de 50 a 800 kPa, com aumentos consecutivos de 50 kPa. Além disso, as vazões foram testadas na faixa de 0 a 4 $m^3 h^{-1}$. Com os dados coletados, procedeu-se então ao ajuste de modelos de predição de vazão de saída em função de vazão e pressão de entrada.

PALAVRA-CHAVE: ensaios laboratoriais, pivô central, irrigação

INTRODUCTION

The center pivot irrigation system has advantages when compared to other systems, especially for use in large areas (O’BRIEN et al. 1998). This irrigation equipment is designed to apply water uniformly along its axis, though factors such as topography, ambient temperature and wind speed may influence irrigation performance. The application uniformity must remain satisfactory to ensure efficient use of resources like water and energy, as well as to properly supply the crop water requirements (MCLEAN et al. 2000).

The pressure along the center pivot lateral line is a critical aspect that may prevent achieving high levels of application uniformity. Pressure varies along the lateral line mainly due to pressure losses (i.e. friction and minor losses) and topography. Center pivots generally have pressure regulating valves (PRV) installed at the inlet of each emitter to ensure steady pressure and constant discharge (LIMA et al. 2003). Such technique, although involves some waste of energy due to pressure dissipated by the regulating valves, is quite useful to attain satisfactory levels of application uniformity. The most common models are spring-valves, where a frame enfolds a piston (LIMA et al. 2007).

If the pressure regulating valves do not operate properly, there will be waste of energy due to pressure losses caused by the valves and, even though, the application uniformity may be unsatisfactory. In addition, the regulated pressure of PRVs is slightly influenced by its inlet pressure as well as the flow rate through it. ISO 10522 (1993) is a standard that states testing methods, requirements and criteria that must be meet by pressure regulating valves used in irrigation. The evaluation of irrigation equipment following standardized methods is important to determine operational characteristics of the equipment and to quantify its performance.

The purpose of this work was to evaluate operational characteristics of pressure regulating valves (PRV) following requirements stated by ISO 10522 (1993). We carried out tests to evaluate regulation uniformity, regulation curve and regulated pressure as function of flow rate and inlet pressure. Tests were performed according to the standard and recommendations of the PRVs manufacturer.

MATERIAL AND METHODS

Testing bench

Tests were undertaken in a testing bench (Figure 1) consisting of a pump and an automated system for pressure control equipped with variable frequency drive and PID controller. The PID controller uses a pressure transmitter, installed at the inlet of the PRV, to calculate an error value between a desired setpoint and a measured pressure and then applies an output signal to the variable frequency drive. The PRV to be tested is installed downstream the electromagnetic flowmeter. The pressure at the inlet and outlet of the PRV was monitored using pressure transmitters. Water temperature was monitored using a temperature transmitter. A needle valve was installed downstream the PRV to enable manually setting the flow rate through the PRV.

Material evaluated

Three models of pressure regulating valves were evaluated: (a) 10 PSI; (b) 15 PSI; and, (c) 20 PSI. The models are named according to their declared preset pressure, that correspond to the pressure at the outlet of the pressure regulator using a reference flow velocity of 1 m s^{-1} (ISO 10522:1993). According to the manufacturer, the Brazilian company Fabrimar, the three models present a nominal pressure of 8 kgf cm^{-2}. The nominal pressure corresponds to the maximum static working pressure at which the PRV is stated to operate under normal service conditions (ISO 10522:1993). In addition, all models have ¾” female threaded connections at inlet and outlet of the valve.

According to ISO 10522 (1993), the evaluated pressure regulating valves may be classified as: (a) according to construction of regulation assembly – single-range pressure regulator; (b) according to construction of pressure regulator – ordinary pressure regulator; (c) according to regulated pressure at zero flow – the regulated pressure is not equal to the inlet pressure at zero flow; (d) according to accuracy level – this classification is part of the results.

Regulation uniformity

Twenty units of each model of PRV were evaluated in this test. The regulated pressure (i. e., the pressure at the PRV outlet) was measured under an inlet pressure of 1.5 times the declared preset pressure and at a flow rate corresponding to a reference velocity of 1 m s^{-1}. Based on the declared preset pressures, tests were carried out under the following inlet pressures: (a) model 10 PSI = 1.05 kgf cm^{-2}; model 15 PSI = 1.58 kgf cm^{-2}; and, model 20 PSI = 2.11 kgf cm^{-2}.

From the obtained results, the coefficient of variation (CV) was calculated according to Eq. 1.

$$CV(\%) = 100\frac{S_p}{\bar{p}} \qquad (1)$$

S_p is the sample standard deviation of the regulated pressures

$\bar{p}$ is the mean regulated pressure of the sample.

Since the PRV models evaluated were classified as ordinary pressure regulators, the mean regulated pressure ($\bar{p}$) shall not deviate from the declared preset pressure by more than 7% and the coefficient of variation shall not be greater than 10% (ISO 10522:1993).

Regulation curve

Three units of each model of PRV were evaluated in this test. The regulated pressure was measured at constant inlet pressure and under flow rates corresponding to the following reference velocities: 0.0, 0.5, 1.0, 1.5, and 2.0 m s^{-1}. The manufacturer requested the laboratory to submit the PRVs also to a flow rate of 3 m^3 h^{-1}. Thus, the flow rates tested were: 0, 0.57, 1.13, 1.70, 2.26, and 3.00 m^3 h^{-1}.

For each model of PRV a chart of regulated pressure as a function of flow rate was plotted. In addition, the chart comprises of three series of data that corresponds to tests carried under the following inlet pressures: (a) 1.5 times the declared preset pressure; (b) 0.8 times the nominal pressure; (c) the inlet pressure at the middle of the regulation range. Thus, model 10 PSI was evaluated under 1.05, 6.40, and 4.50 kgf cm^{-2}; model 15 PSI was evaluated under 1.58, 6.40, and 4.25 kgf cm^{-2}; model 20 PSI was evaluated under 2.11, 6.40, and 4.5 kgf cm^{-2}.

By increasing the reference velocity by 1 m s^{-1}, from 0.5 to 1.5 m s^{-1} and from 1 to 2 m s^{-1}, the regulated pressure shall not vary by more than 10% from the declared preset pressure for PRVs of accuracy level A and 20% for PRVs of accuracy level B (ISO 10522, 1993).

Regulated pressure as function of flow rate and inlet pressure

Three units of each model of PRV were evaluated in this test. ISO 10522 (1993) describes a test to determine the regulated pressure as function of inlet pressures, at constant flow rate. In addition to the standard requirements, the manufacturer demanded the laboratory to undertake the test within a range of flow rates.

Inlet pressures ranged from 0.5 to 8.0 kgf cm^{-2} in intervals of 0.5 kgf cm^{-2}. Tests were carried out systematically increasing and decreasing inlet pressures in order to factor in hysteresis effects. For the model 10 PSI, the flow rates tested were 0.57, 1.13, 1.70, 2.26, 3.00 and 3.60 m^3 h^{-1}. For the models 15 PSI and 20 PSI, the same values were tested, except the last one, which was 4.00 m^3 h^{-1}.

Experimental data gathered during the test were employed to fit a mathematical model for each PRV model. The mathematical model enables to estimate the regulated pressure as function of flow rate and inlet pressure (Eq. 2). The coefficients were determined using the Least Square Method and the Solver suplement of Microsoft Excel®.

$$P = a + b\,Q + \frac{c}{1 + e^{\left(\frac{d - P_{in}}{f}\right)}} \qquad (2)$$

P is the regulated pressure (kgf cm^{-2})

P_{in} is the inlet pressure (kgf cm^{-2})

Q is the flow rate through the PRV (m^3 h^{-1})

a, b, c, d, f are coefficients.

The goodness of fit was assessed based on the Root Mean Square Error (RMSE), 1:1 straight line and distribution of frequency of errors. RMSE was calculated by Eq. 3.

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N} (\hat{P} - P)^2}{N}} \qquad (3)$$

$\hat{P}$ is the estimated value of regulated pressure (kgf cm^{-2})

P is the measured regulated pressure (kgf cm^{-2})

N: Number of pair of values.

The relative error between estimated and measured values (δ) was determined by Eq. 4.

$$\delta(\%) = 100\,\frac{|\hat{P} - P|}{P} \qquad (4)$$

δ is the relative error (%)

$\hat{P}$ is the estimated value of regulated pressure (kgf cm^{-2})

P is the measured regulated pressure (kgf cm^{-2}).

RESULTS AND DISCUSSION

Regulation uniformity

Table 1 shows results from the regulation uniformity test. The coefficient of variation was smaller than 10% for all the evaluated models and thus the PRVs meet one of the criteria stated by ISO 10522 (1993). The low values of CV indicate a proper quality control on the manufacturing process. The regulated pressure was similar when twenty samples of each model was evaluated under the same testing conditions.

The deviation between the average regulated pressure and the declared preset pressure was lower than 7% for models 15 PSI and 20 PSI and higher than that threshold for the model 10 PSI. Therefore, only the model 10 PSI does not meet one of the criteria defined by ISO 10522 (1993). One of the solutions to make this PRV model to comply with the standard would consist in changing the declared preset pressure to a value closer to 0.62 kgf cm^{-2} (8.82 PSI).

Regulation curve

Figure 2 shows the regulation curves obtained from testing the three PRV models. The regulated pressure at flow rates higher than zero were similar under the three inlet pressures evaluated. It indicates that all models operated properly under a range of testing conditions. The regulated pressure at zero flow was sligtly higher than the declared preset pressure, but it is tolerated by the standard.

Figure 3 presents deviation between regulated pressure and declared preset pressure when the reference flow velocity varied from 0.5 to 1.5 m s^{-1} and from 1.0 to 2.0 m s^{-1}. Regarding to the requirement “regulation curve”, results shown in this figure enable to classify the models according to accuracy level. The deviation of values for the models 10 PSI and 20 PSI was always lower than 10%, hence these models may be classified as pressure regulators with accuracy level A. On the other hand, the model 15 PSI presented values lower than 20% and thus it may be considered a pressure regulator with accuracy level B (ISO 10522, 1993).

Regulated pressure as function of flow rate and inlet pressure

The coefficients of Eq. 2 were fitted based on data gathered during the tests (Table 2). Each model of PRV has a specific equation that enables to estimate the regulated pressure as function of flow rate through the valve and pressure at its inlet. The RMSE values and the limits of use of the equations are also presented in Table 2.

Figure 4 enables comparison between measured and estimated values of regulated pressure within a plot that also has a straight line 1:1. These charts indicates accuracy of estimated values of regulated pressures using the fitted models. In addition, charts presenting cumulative frequency of relative errors on estimating regulated pressure are also shown. These charts enable to quantity accuracy while using the models. Analyzing the model 10 PSI, 95% of estimated values presented relative error lower than 7.9% and 83.5% of estimated values presented relative error up to 5%. Analyzing the model 15 PSI, 95% of estimated values presented relative error lower than 7.4% and 86.7% of estimated values presented relative error up to 5%. Finally, analyzing the model 10 PSI, 95% of estimated values presented relative error lower than 6.0% and 90.2% of estimated values presented relative error up to 5%.

CONCLUSION

The evaluated models of pressure regulating valves operated properly within the operating range recommended by the manufacturer. The regulation uniformity results indicate proper quality on the manufacturing process. The regulation curves indicate that regulated pressure was attained varying inlet pressure and flow rate according to the standardized test method. The models to estimate regulated pressure as function of inlet pressure and flow rate are not described by the standard, though it should be included in further revisions of it. Such models are helpful while designing center pivots.

The models of pressure regulating valves comply with the assessed requirements of ISO 10522 (1993).

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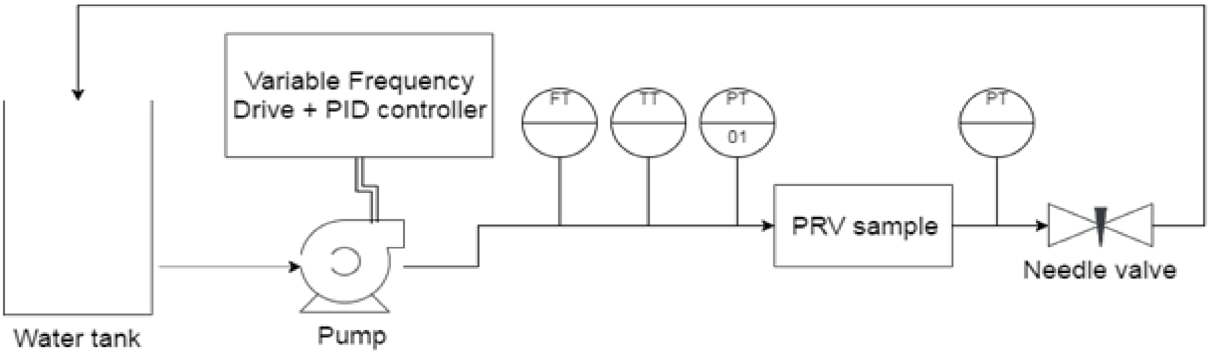

Figure 1. Instrumentation flowchart of the testing bench for evaluation of pressure regulating valves (FT: flow transmitter; TT: temperature transmitter; PT: pressure transmitter)

Table 1. Results from the regulation uniformity test

Parameter	PRV model		
	10 PSI	15 PSI	20 PSI
Declared present pressure (kgf cm^{-2})	0.70	1.05	1.41
Mean regulated pressure (kgf cm^{-2})	0.62	1.06	1.37
Standard deviation of the regulated pressures (kgf cm^{-2})	0.0217	0.0204	0.0365
Coefficient of variation (%)	3.5	1.9	2.7
Deviation between the mean regulated pressure and the declared present pressure (%)	11.5	0.7	2.3

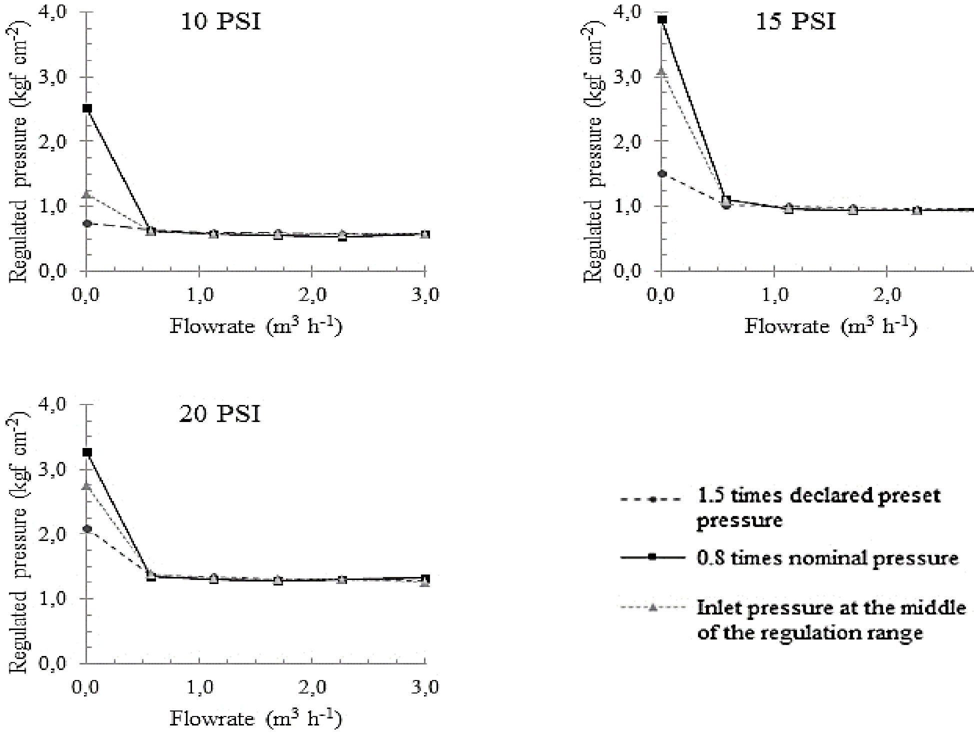

Figure 2. Regulation curves

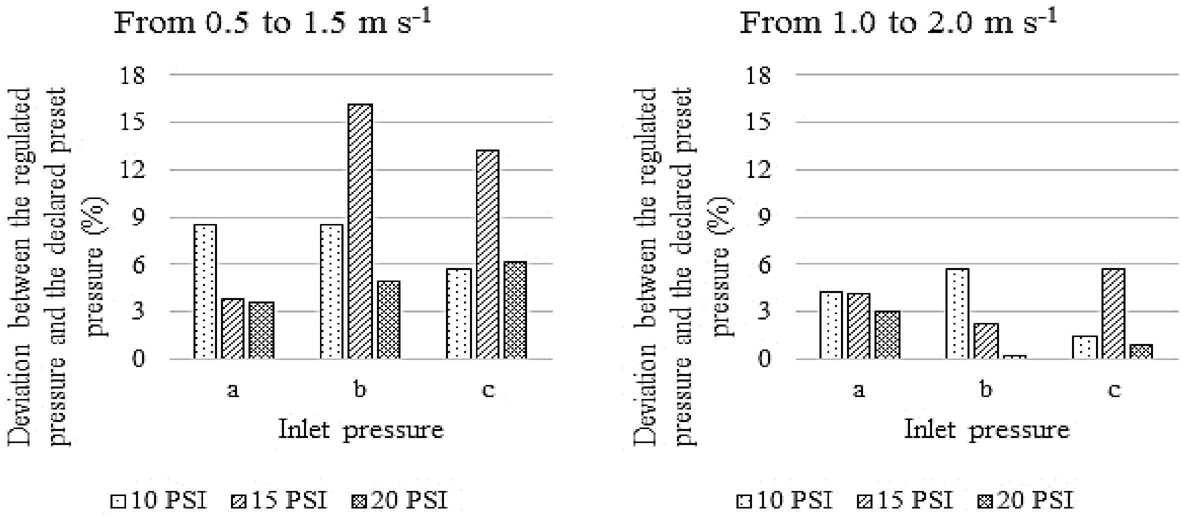

Figure 3. Deviation between the regulated pressure and the declared preset pressure when the reference flow velocity varied from 0.5 to 1.5 m s^{-1} and from 1.0 to 2.0 m s^{-1}

Table 2. Coefficients of the equations to estimate regulated pressure as function of flow rate and inlet pressure

Model	Equation coefficients					RMSE	Limits of use	
	a	*b*	*c*	*d*	*f*		*Q* (m^3 h^{-1})	P_{in} (kgf cm^{-2})
10 PSI	-4.5089	-0.0292	5.1947	-0.8593	0.4317	0.0243	0.57 to 3.65	0.5 to 8.0
15 PSI	-4.4262	-0.0446	5.5458	-0.3072	0.3919	0.0383	0.57 to 4.00	0.5 to 8.0
20 PSI	0.2169	-0.0363	1.2187	0.8953	0.2821	0.0336	0.57 to 4.00	0.5 to 8.0

Figure 4. Measured (P_{meas}) x estimated (P_{est}) values of regulated pressure and cumulative frequency of relative errors on estimating regulated pressure