GENETIC ALGORITHM CALIBRATION OF THE TRANSIENT FLOW MODEL FOR THE WATER SUPPLY SYSTEM OF A HYDROPOWER PLANT

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The aim of this paper is to highlight the simplicity of a Genetic Algorithm (GA) based method to calibrate a transient flow model. To do this, numerical tests were conducted in a hypothetical hydraulic system at small scale, consisting of the same main parts as the water supply system of a hydropower plant. The test system consists of a reservoir joined to a throttled surge-tank by a pipe ("headrace tunnel"), and then this tank is connected to a downstream valve by another pipe ("penstock"). The valve upstream power plant's turbine is the dynamic element that initiates transient events. Theoretical results were validated using in situ measurements at the water supply system of Râul-Mare Retezat hydropower plant.

Keywords: transient flow, Genetic Algorithm, model calibration, hydropower plant

1. Introduction

Usually, the slow variable transient flow along the headrace tunnel and inside the surge tank (known as mass-oscillations and described by ordinary differential equations) is separately analyzed from the sudden variable transient flow along the penstock (known as waterhammer, governed by nonlinear partial differential equations), although the unsteady hydraulic processes occurs into the same physical system.

In a previous paper [1], the Algebraic Waterhammer Method (AWM) was adapted to study the transient flow along the whole hydraulic way between reservoir and power plant's turbines (including the main headrace tunnel, the secondary intake shaft, the main surge tank and the penstock). The inertia and friction effects for the water column movement in shaft/tank, as well as the headloss in the connectors to these devices were also taken into account [2].

However, the system parameters used in such a model can be only roughly estimated (Darcy-Weisbach friction factors for headrace and penstock – from measurements in steady flow regime) or approximated upon standard references and geometrical data (for orifice parameters at connector with tank/shaft). If field

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data are collected, the model calibration for a real world system should be better when the head and flow vary widely in a short time interval.

The inverse transient analysis was presented for example by other authors in a matrix-based formulation [3], or using a direct-equation approach based on the classical Method of Characteristics (MOC) [4], both works appealing the Levenberg-Marquardt minimization algorithm in a different manner.

The aim of this paper is to highlight the simplicity of a Genetic Algorithm (GA) based method to calibrate a transient flow model. Some theoretical aspects are firstly presented using numerical tests for a hypothetical hydraulic system, consisting of the same main parts as the water supply system of a hydropower plant, as shown in Fig. 1. The test system consists of a reservoir having the head H_r, joined to a throttled surge-tank by a pipe – *headrace tunnel*, and then this tank is connected to a downstream valve by another pipe – *penstock*. The dynamic element that initiates transient events is the valve upstream power plant's turbine.

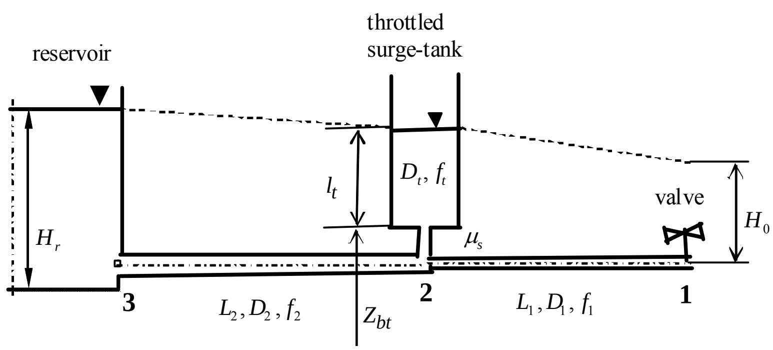

Fig. 1. Sketch of test system (initial conditions)

The model parameters are: the Darcy-Weisbach friction coefficients along the two pipes and into the surge-tank, f_1, f_2 and f_t, together with the orifice parameter for restricted entrance in the tank, μ_s.

Extensions of this GA approach to more complexes, real world systems are simple and straightforward. Such application is described, in brief, for the water supply system of the Râul-Mare Retezat hydropower plant.

2. The transient flow mathematical model

It is known that the transient flow is governed by two quasi-linear partial differential equations obtained from momentum and mass conservation [5]:

$$\frac{1}{gA}\frac{\partial Q}{\partial t}+\frac{\partial H}{\partial x}+\frac{fQ|Q|}{2gDA^2}=0 \tag{1}$$

$$\frac{\partial H}{\partial t}+\frac{a^2}{gA}\frac{\partial Q}{\partial x}=0 \tag{2}$$

where x is the distance along pipe's centreline, t is the time, $Q(x,t)$ is the flow discharge, $H(x,t)$ is the piezometric head, $A=\pi D^2/4$ is the cross sectional pipe area, D is the pipe diameter, f is the Darcy-Weisbach friction coefficient, a is the wave speed and g is the gravity. The convective and the slope terms are accepted as negligible and were ignored.

Numerical methods for solving the transient flow equations are well illustrated in literature ([2], [5]–[7]), but practical applications are rather devoted to water distribution networks ([8], [9]). The physical and mathematical conditions that lead to a uniquely determined solution of these equations are presented in Hâncu and Marin [10].

In the classical MOC ([5], [6]), the momentum and continuity equations are combined to form the compatibility equations in Q and H as follows:

$$dH \pm BdQ \pm \frac{r}{\Delta x}Q|Q|dx=0 \tag{3}$$

where $B=a/(gA)$ and $r=f\Delta x/\left(2gDA^2\right)$. These relations are valid only along the C^+ and C^- characteristic lines defined by the equations $dx/dt=\pm a$, or by $\Delta x=\pm a\Delta t$ on a computational $\{x,t\}$ grid, as shown in Figure 2. If the flow conditions (H,Q) are known at time t, the equation (3) can be integrated along AD and BD lines to provide two relations for H and Q at point D, at $(t+\Delta t)$. For the frictional term integration, Karney and McInnis [2] proposed a form as:

$$\int_{\mathrm{A}}^{\mathrm{D}} Q|Q|dx=\Delta x|Q_{\mathrm{A}}|\left[Q_{\mathrm{A}}+\varepsilon\left(Q_{\mathrm{D}}-Q_{\mathrm{A}}\right)\right], \tag{4}$$

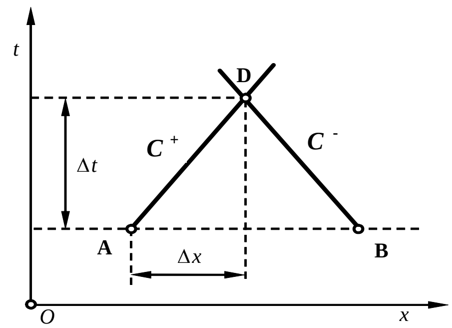

Fig. 2. Computational grid for solving transient flow in classical MOC

where ε is a linearization constant between 0 and 1. Then

$$\begin{aligned} H_{\mathrm{D}} &= C_P - B_P Q_{\mathrm{D}} \\ H_{\mathrm{D}} &= C_M + B_M Q_{\mathrm{D}}, \end{aligned} \tag{5}$$

where

$$\begin{aligned} C_P &= H_{\mathrm{A}} + Q_{\mathrm{A}}\left[B - r\left|Q_{\mathrm{A}}\right|(1-\varepsilon)\right] \\ C_M &= H_{\mathrm{B}} - Q_{\mathrm{B}}\left[B - r\left|Q_{\mathrm{B}}\right|(1-\varepsilon)\right], \end{aligned} \quad \text{and} \quad \begin{aligned} B_P &= B + \varepsilon r\left|Q_{\mathrm{A}}\right| \\ B_M &= B + \varepsilon r\left|Q_{\mathrm{B}}\right|, \end{aligned} \tag{6}$$

with inferior index *P* attached to C^+, and index *M* attached to C^-.

After eliminating the H_{D} value from equations (5), the Q_{D} value is obtained as:

$$Q_{\mathrm{D}} = \frac{C_P - C_M}{B_P + B_M} \tag{7}$$

and then the H_{D} value can be easily computed.

The AWM is particularly convenient for transient calculations in piping systems, using the same conception as MOC. The equations for AWM may be applied over several reaches of Δx length [5, pages 66-70], with no need to compute the transient at interior sections.

For a pipe with *p* reaches (Figure 3), these equations may be written as follows, for the time step *j:*

$$\begin{aligned} C^+ &: \quad H_{\mathrm{B}}(j) = C_{\mathrm{A}}(j-p) - B_{\mathrm{A}}(j-p) Q_{\mathrm{B}}(j) \\ C^- &: \quad H_{\mathrm{A}}(j) = C_{\mathrm{B}}(j-p) + B_{\mathrm{B}}(j-p) Q_{\mathrm{A}}(j) \end{aligned} \tag{8}$$

in which

$$\begin{aligned}
C_A(j-p) &= H_A(j-p) + Q_A(j-p)\left[B - R\left|Q_A(j-p)\right|(1-\varepsilon)\right]\\
C_B(j-p) &= H_B(j-p) - Q_B(j-p)\left[B - R\left|Q_B(j-p)\right|(1-\varepsilon)\right]\\
B_A(j-p) &= B + \varepsilon R\left|Q_A(j-p)\right|\\
B_B(j-p) &= B + \varepsilon R\left|Q_B(j-p)\right|
\end{aligned}, \qquad (9)$$

where $R = pr$.

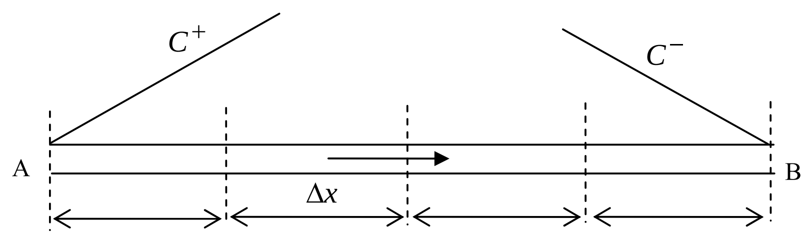

Fig. 3. Pipe with *p* reaches

By starting computations within the $\{x,t\}$ grid with $(p-1)$ time steps Δt before the beginning of transient, and storing the steady state values for $H_A(j)$, $Q_A(j)$, $H_B(j)$, $Q_B(j)$, with $j = 1, 2, ..., p$, the AWM equations can now be solved for $j = (p+1)$, $(p+2), \ldots$ etc, together with the boundary conditions at end points A and B.

For the system shown in Figure 1, the selection of number p_1 and p_2 of the reaches in each pipe must be such that Δt is common, i.e.:

$$\Delta t = \frac{L_1}{p_1 a_1} = \frac{L_2}{p_2 a_2} \qquad (10)$$

and this is given by small adjustments of the celerity a_1 and a_2.

The only sections with transient computation will be 1, 2 and 3 from Figure 1.

• For section 1, an equation as C^+: $H_1(j) = C_2(j-p_1) - B_2(j-p_1)Q_1(j)$ is solved along with the boundary condition for valve closing $Q_1(j) = \frac{Q_0}{\sqrt{H_0}}\sqrt{H_1(j)}\tau(j)$, where $\tau = 1$ for Q_0 and $\tau = 0$ after the valve closure. In C_2 and B_2, the discharge $Q_2^-(j-p_1)$, just downstream the tank (Figure 4) must be used.

• For section 3, an equation as C^-: $H_3(j)=C_2(j-p_2)+B_2(j-p_2)Q_3(j)=H_r$ is solved (if the entrance head losses are neglected), and the discharge $Q_2^+(j-p_2)$, just upstream the tank, must be used in C_2 and B_2.

• For section 2, the equations C^-: $H_2(j)=C_1(j-p_1)+B_1(j-p_1)Q_2^-(j)$ and C^+: $H_2(j)=C_3(j-p_2)-B_3(j-p_2)Q_2^+(j)$ are to be solved together with the continuity equation:

$$Q_2^+(j)-Q_2^-(j)-Q_c(j)=0, \tag{11}$$

the orifice discharge expression:

$$Q_c(j)=s\mu_s\sqrt{s[H_2(j)-H_b(j)]}, \tag{12}$$

and the lumped model for inertia and friction effects in the tank:

$$H_b(j)-H_w(j)=C_r^{'}+C_r^{''}Q_c(j), \tag{13}$$

where Q_c is the flow discharge into the tank, μ_s is the orifice parameter, $s=sign[Q_c(j)]=\pm 1$, H_b is the head at the base of the tank, $H_w=Z_{bt}+l_t$ is the water surface elevation, Z_{bt} is the base elevation of the tank and l_t is the length of the water column above Z_{bt} (Figure 4). The expressions of $C_r^{'}$ and $C_r^{''}$ are:

$$\begin{aligned} C_r^{'} &= H_w(j-1)-H_b(j-1)-\frac{2l_t(j-1)}{gA_t\Delta t}Q_c(j-1) \\ C_r^{''} &= \frac{2l_t(j-1)}{gA_t\Delta t}+\frac{f_t l_t(j-1)}{gD_t A_t^2}\left|Q_c(j-1)\right| \end{aligned} \tag{14}$$

where D_t, A_t and f_t are the tank diameter, cross-sectional area and friction coefficient respectively.

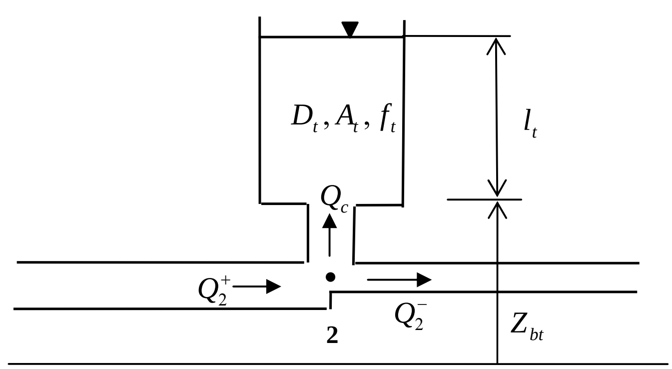

Fig. 4. Throttled surge tank

Using the above relations, a quadratic equation in $Q_c(j)$ is obtained as:

$$Q_c^2(j)+2\alpha Q_c(j)+\beta=0, \tag{15}$$

having as solution:

$$Q_c(j)=-\alpha+s\sqrt{\alpha^2-\beta}, \tag{16}$$

where $s=sign(C_c-C_b)$; $\alpha=\frac{1}{2}\mu_s^2 s(B_b+B_c)$; $\beta=\mu_s^2 s(C_b-C_c)$; $B_b=C_r^{"}+b_0$;

$b_0=\frac{\Delta t}{2A_t}$; $B_c=\left(\frac{1}{B_3(j-p_2)}+\frac{1}{B_1(j-p_1)}\right)^{-1}$; $C_c=B_c\left[\frac{C_3(j-p_2)}{B_3(j-p_2)}+\frac{C_1(j-p_1)}{B_1(j-p_1)}\right]$ and $C_b=C_r^{'}+H_w(j-1)+b_0Q_c(j-1)$.

Once the external flow at time step j is computed, all other interest parameters, i.e.: $H_b(j)$, $H_w(j)$, $H_2(j)$, $Q_2^+(j)$ and $Q_2^-(j)$ can also be obtained with appropriate relations, namely the continuity equation for the tank: $H_w(j)=H_w(j-1)+b_0[Q_c(j-1)+Q_c(j)]$; then $H_b(j)$ from (13); $H_2(j)$ from (12) and, finally, $Q_2^-(j)$ and $Q_2^+(j)$ from C^- and C^+ equations.

This AWM was used to produce some data sets for numerical tests with GA based method of calibration. The relevant parameters are as follows: $L_1=1000$ m; $D_1=0.6$ m; $f_1=0.024$; $L_2=2000$ m; D_2=0.75m; f_2=0.016; H_r=75m; Q_0=0.75m^3/s; a=1000m/s; $Z_{bt}=2.3$ m; $D_t=0.6$ m; $f_t=0.02$ and $\mu_s=0.6$. The valve is assumed to close linearly in either 6 or 3 seconds. A time step $\Delta t=0.5$ s was used and 100 values of the lengths of the water column above Z_{bt} in the first 100 seconds were retained as *recorded data* for calibration. A friction linearization term $\varepsilon=0.8$ was supposed.

3. Genetic Algorithm based method of calibration

In this work, the Darcy-Weisbach friction factors f_1, f_2, f_t and the orifice parameter μ_s of entrance into the tank are accepted as calibration parameters. Their correct values are intended to be obtained using a time-succession of known values for the length of water column (or water level) in the surge tank.

GAs were proved useful in a variety of optimization problems because of their wide flexibility and ability to find near optimal or optimal solutions without computational difficulties [11]. The GA approach does not require some restrictive conditions as the traditional optimization techniques (e.g. continuity, differentiability of the first or second order etc). GAs are a class of stochastic optimization methods that simulate the process of evolution by natural selection and genetic inheritance.

In a GA, properties of a numerical optimization problem are defined by their biological analogues (e.g. potential solutions are represented as individuals within the environment; the value of the objective function for a potential solution represents the fitness of this solution to the environment; a group of potential solutions at a GA iteration is called a population or a generation). The individuals within the population compete for survival based on their fitness: those with more fitness have a higher likelihood of surviving and influencing future generations. Through this competition, the population evolves towards high-performing individuals in the next generation.

Decision variables of a potential solution in optimization problems are analogous to biological genes of an individual or chromosome, and their values influence the fitness (objective function value).

The first step in a GA is to randomly generate an initial population of coded individuals. In this calibration problem, the decision variables for each potential solution are the values of f_1, f_2, f_t and μ_s, coded as real numbers. A population size of 80 individuals was used and for each solution, the values of f_1, f_2 and f_t were randomly generated within the plausible (0÷0.05) range. For μ_s, a (0÷1) range was accepted.

The objective function is defined as [12]:

$$\min\left\{ f(\mathbf{X}) = \sum_{j=1}^{J} \left[\bar{l}_t(j) - l_t(j,\mathbf{X}) \right]^2 \right\}, \tag{17}$$

where $\mathbf{X}$=(f_1, f_2, f_t, μ_s) is the decision variables vector, J is the number of *measured data* used in calibration, $\bar{l}_t(j)$ is the *j*-th *recorded* length of water column in tank, and $l_t(j,\mathbf{X})$ is the *j*-th length of water column for the $\mathbf{X}$ vector values. Because $f(\mathbf{X}) \geq 0$, the fitness function as:

$$E_v(\mathbf{X}_i) = \frac{S - f(\mathbf{X}_i)}{S} \tag{18}$$

where $S = \max\limits_{i,p}\{f(\mathbf{X}_i)\}$ is the greatest value of $f(\mathbf{X})$ between all the individuals *i* and all generation *p* until the current one, will be most close to 1 when $f(\mathbf{X})$ is near 0. Such a function was used to evaluate the individual fitness.

A second generation of potential solutions evolves, not by automatically selecting individuals from previous generation according to their fitness, but using a procedure which allows a higher selection probability to individuals with a high fitness. Tournament selection was used here: four individuals are randomly selected out of the current population with replacement, and the more fit one is selected for reproduction. After a new selection, the pair of two parent solutions generates two children solutions by crossover and mutation operators. Crossover is performed if $r < p_c$, where r is a random number uniformly distributed between 0 and 1, and p_c is the probability of crossover, imposed here as $p_c = 0.9$. The arithmetic crossover with linear combination of the two parents was used as crossover operator. The mutation operator is applied with a small probability ($p_m = 0.05$), to prevent a population from converging too quickly in a local optimum. A gene (decision variable) may be randomly selected and mutated to a different value. Here the nonuniform mutation operator was used.

The process of selection, crossover and mutation is repeated until a new generation is completed. After evaluation of new individuals' fitness, the above steps are repeated and successive generations will be produced, to improve the performance of the population.

The GA is stopped after 30000 generations, and the best solution that was found during the run is accepted as optimal calibration vector. The computer program for this problem includes, as particular items, a procedure for introducing the input data, and a procedure to compute the transient regime with AWM, for a given (f_1, f_2, f_t, μ_s) set. The rest of the program is generally useful for any other optimization problem.

4. Numerical results

An initial analysis considered the *recorded data* for closure-time of 6 seconds. The travel time for a wave from valve to the tank is 1s, and to the reservoir is 3s. The flow discharge into the tank begins after 1s, and the maximum water level is reached after 24s, being followed by a slow decreasing which continues after 100s as well.

Table 1 shows the calibration results obtained in 10 runs, with the first 50 *recorded data*, and with all 100 values respectively.

One can see that for the friction factors of the two pipes, the calibrated values are very good in both sets of runs. In all runs, the computed value of the friction coefficient of the pipe between reservoir and surge tank is identical to its true value. The friction factor in the tank is however more unstable, but the mean value over the second set of runs differs only by 1.75% from the true value. A plausible justification should be in his reduced influence upon the hydraulic process. Concerning the orifice parameter of the throttled entrance, μ_s, the mean value obtained in runs with more *recorded data* may be accepted as satisfactory (less than 1% difference).

A similar analysis was performed for a closure time of 3s. Table 2 shows only the mean values and absolute differences in % over 10 runs.

Table 1

Calibration results in 10 runs (closure time 6s)

Run	With 50 *recorded data*				With 100 *recorded data*			
	f_1	f_2	f_t	μ_s	f_1	f_2	f_t	μ_s
1	0.024	0.016	0.0253	0.6543	0.0239	0.016	0.0202	0.6017
2	0.0239	0.016	0.0202	0.602	0.0238	0.016	0.0167	0.5726
3	0.0241	0.016	0.027	0.6761	0.024	0.016	0.0219	0.618
4	0.024	0.016	0.0232	0.6311	0.0239	0.016	0.017	0.5744
5	0.0239	0.016	0.0216	0.6154	0.0238	0.016	0.0165	0.5709
6	0.024	0.016	0.0222	0.6208	0.0239	0.016	0.0181	0.5833
7	0.024	0.016	0.0244	0.6443	0.024	0.016	0.025	0.6512
8	0.0239	0.016	0.0204	0.6037	0.024	0.016	0.0232	0.631
9	0.024	0.016	0.0218	0.6176	0.0241	0.016	0.0265	0.6689
10	0.024	0.016	0.0224	0.6231	0.0239	0.016	0.0184	0.5862
mean	0.02398	0.016	0.02285	0.62884	0.02393	0.016	0.02035	0.60582
% $\lvert$difference$\rvert$	0.083	0	14.25	4.8	0.292	0	1.75	0.97

Table 2

Synthetic results for 10 runs (closure time 3s)

	With 50 *recorded data*				With 100 *recorded data*			
	f_1	f_2	f_t	μ_s	f_1	f_2	f_t	μ_s
mean	0.0238	0.016	0.01901	0.59243	0.02387	0.016	0.02109	0.61133
% $\lvert$difference$\rvert$	0.83	0	4.95	1.26	0.54	0	5.45	1.89

In this case, pipe's friction coefficients still remain close to the true values (less than 1% difference). Some better mean values were obtained for friction factor in tank, and for orifice parameter when the first 50 *recorded data* were used. This is probably due to the more intense hydraulic process in the tank at the beginning of transient.

However, if real-world recorded data are used, the ε value of friction linearization term may be assigned as a new calibration parameter, in the same way as the friction factors and orifice parameter. To verify this, the 100 *recorded data* for closure time 6 seconds were used and ε has been introduced among the calibration parameters. For initial population, ε was randomly generated in the $(0 \div 1)$ range.

Eight runs were performed, each over 30000 generations, and the average values for calibration parameters are as follows: f_1=0.02396; f_2=0.016; f_t=0.02056; μ_s=0.60644 and ε=0.7958 (compared with the true values 0.024; 0.016; 0.02; 0.6 and 0.8 used to generate the 100 *recorded data*). Obviously, GA is able to obtain some average values of the five parameters for several runs, which are practically the same as the true ones.

In a last sensitivity analysis, all *recorded data* are assumed to be affected by measurement errors. Using the 100 correct data from the run with t_c=6s, 3 new sets of 100 data were randomly generated by adding some normal distributed error terms with 0 mean and 0.05m standard deviation (5cm being a major measurement error).

For each non-perfect data set, GA was run over various number of generations, accepting the five calibration parameters already presented. The mean values from 5 runs for each altered data set are shown in Table 3, together with the true values and the mean values over the three altered sets.

One can see that pipe friction coefficient f_2 (between the reservoir and the surge tank) is practically insensitive to the errors distribution in altered data sets, while the others parameters are strongly influenced. However, the mean values (last column in Table 3) seem to be reasonably good.

For example, the error terms added in the second set of altered data is shown in Figure 5.

Table 3

The mean values of calibration parameters for the 3 altered data sets

Parameter	altered set 1	altered set 2	altered set 3	true values	mean values on 3 altered sets
f_1	0.0213	0.0228	0.02616	0.024	0.02342
f_2	0.01608	0.01612	0.0159	0.016	0.01603
f_c	0.01958	0.02044	0.02572	0.020	0.02191
μ_s	0.5757	0.6622	0.6824	0.600	0.6401
ε	0.9982	0.6245	0.7186	0.800	0.7804

Referring to these results, the only statement to be formulated is that, in real world measurements, to record 100 data with absolutely random errors is rather an unusual event. If some errors appear, however, in the recorded data, they should be rather the systematic ones and related to the measurement devices or experimental protocol.

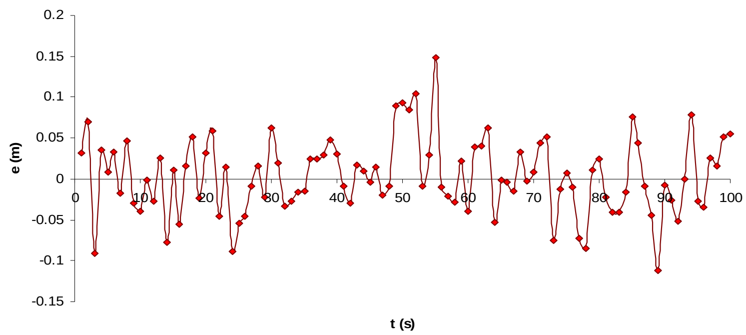

Fig. 5. Deviations from correct values of the second altered data set

5. In situ case study

To prove the GA based method qualities to calibrate the transient flow model for a real world water supply system, some recorded data sets at the Râul Mare - Retezat hydropower plant were used.

Geometrical data of the hydraulic system are as follows: length and diameter of headrace tunnel L_2=18500m, D_2=4.9m; length and diameter of penstock L_1=1000m, D_1=3.35m; height and diameter of surge tank L_t=148m, D_t=5.9m (having an upper chamber above L_t). The connector between the headrace tunnel and vertical shaft of surge tank is assumed with different values for the orifice parameter at inlet flow μ_+, and outlet flow μ_-, respectively. The friction headloss within surge tank was ignored ($f_t = 0$), but a closure law as $\tau(t) = (1 - t/T_i)^m$ reduces the discharge at valve during the closure time T_i. The values of m and T_i were also accepted as calibration parameters.

The installed discharge is of 70m^3/s in two turbines. The water level (column length) variation in surge tank was estimated by the pressure records of a transducer included in a HidroSmart System and placed just downstream of surge tank.

From many sets of recorded data, only one is used here for illustration, within following conditions: reservoir water level 977.84 MASL, one turbine in operation at steady flow discharge Q_0=26.1m^3/s, normal stopping of the turbine, tank water levels recorded at 3.2s time-interval.

The results of 5 runs with GA calibration are shown in Table 4. One can observe that all runs provide almost the same values for the calibration parameters. The first run values were used in the transient hydraulic model and the computed results are shown in Figure 6, comparatively with the ones recorded in situ.

Table 4

Results of 5 run for the calibration parameters of the Râul-Mare Retezat hydropower plant

	f_1	f_2	μ_+	μ_-	T_i	m	ε
Run 1	0.02	0.018	8.665	6.0904	55.12	3	0.8619
Run 2	0.02	0.018	8.6628	6.0905	55.1141	3	0.8636
Run 3	0.02	0.018	8.6645	6.094	55.1193	3	0.8623
Run 4	0.02	0.0185	8.7664	6.1189	60	3.448	0.9042
Run 5	0.02	0.0184	8.7546	6.1121	60	3.4301	0.8935
Mean values	**0.02**	**0.01818**	**8.70266**	**6.10118**	**57.0707**	**3.17562**	**0.8771**

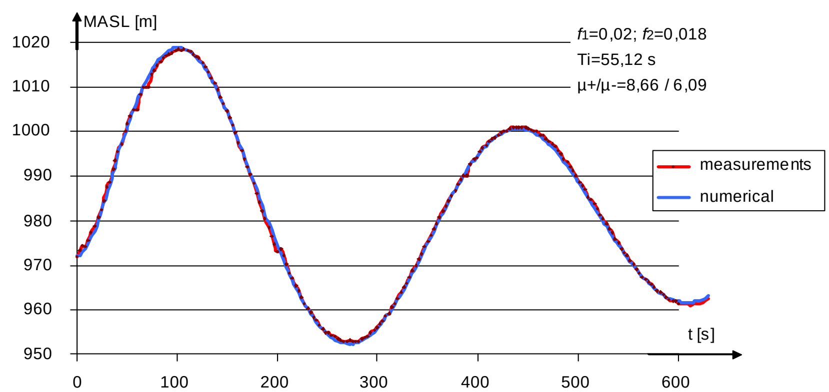

Fig. 6. Comparison between in situ measurements and numerical results for water level in the surge tank

Obviously, GA calibration is able to give some valuable values of the interest parameters for such a transient hydraulic model at real world scale.

6. Conclusions

The aim of this paper was to present a Genetic Algorithm based method calibration for the transient flow mathematical model along the hydraulic way between reservoir and hydropower plant's turbine. The Algebraic Waterhammer Method is used for numerical integration of the waterhammer equations within this complex hydraulic system, including headrace tunnel, penstock, surge tank with throttled connector, control valve etc.

Firstly, a small-scale test system and *recorded data* obtained by numerical simulation were used to study the qualities of the proposed calibration model.

Because of the encouraging results in various sensitivity analyses, the GA calibration model was then tested for a real world water supply system at the Râul-Mare Retezat hydropower plant. The computed results prove the ability and flexibility of the proposed calibration method, if some accurate in situ recorded data are available.

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