Automation of vehicle dynamic calculations

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The developed applications software permits to automate dynamics calculations in the early stages of designing and does not require knowledge from designer in the fields of computational mathematics and programming. It allows to determine transient and stationary behaviour of a broad class of discrete non-linear mechanical systems subjected to deterministic or stochastic excitations. It also enables to optimize parameters in accordance with different criteria in the automatic mode. The results of optimizing the lorry suspension and the technological machines of building industry are presented in brief.

INTRODUCTION

The current trend is to leave to engineers the informal part of designing dynamic systems, namely, the problem formulation and interpretation of the results. Considerable and generally acknowledged results have been obtained in the CAD and CAE fields. Much has been done all over the world to develop general purpose computer codes for dynamics analysis and synthesis (ref. 1, 2). In this article we try to offer engineer-oriented alternative tools for automating dynamics calculation of systems consisting of rigid bodies which are connected by means of non-inertial elastic and damping links with arbitrary non-linear characteristics and are subjected to deterministic or stochastic excitations.

1. Tools of investigations

For carrying out of dynamic calculations applications software (see Fig. 1) is proposed. It consists of bonded components, however, each ingredient has stand-alone capabilities. In the case of the non-full mathematical description of an object, an identification code Disint (ref. 3) allows to construct models for machines or their separate parts in terms of algebraic relations, differential or finite - difference equations. Utilization of planned experiments code Pln (ref. 4) essentially reduce expenses for experimental investigations.

After obtaining the model structure and the parameters, the simulation system Imita (ref. 5) can be used. It enables solutions to be found of automatically constructed equations of motion.

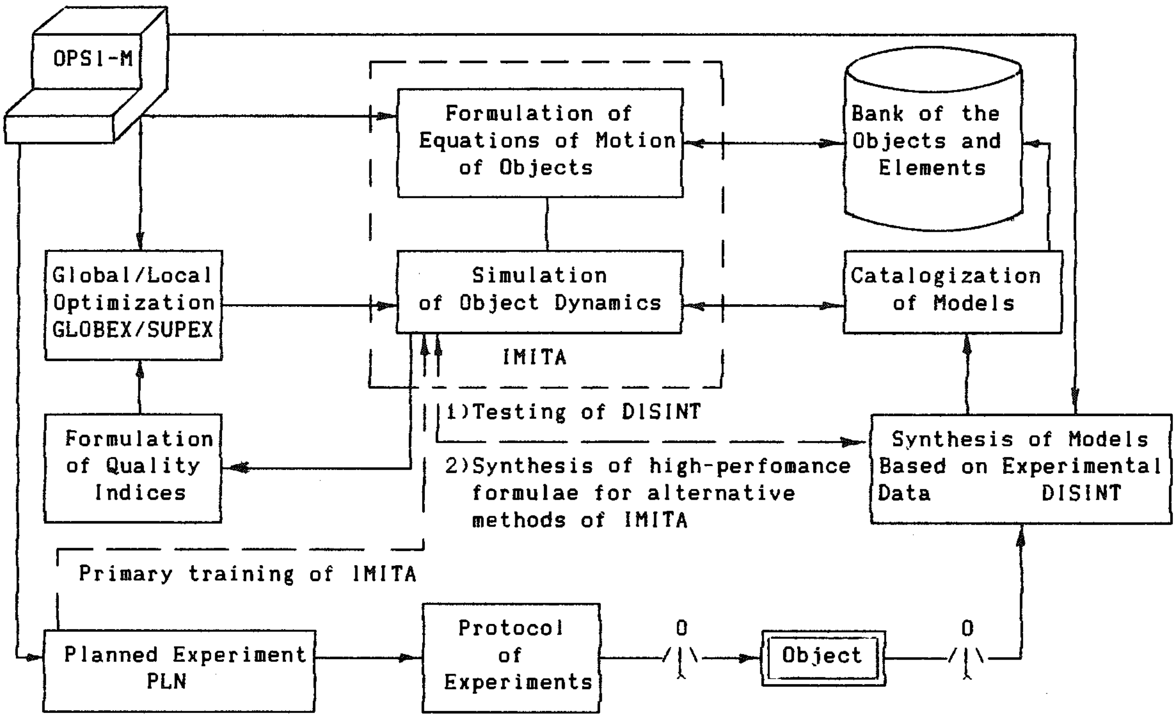

Fig. 1. Block diagram of automated system for dynamic calculations

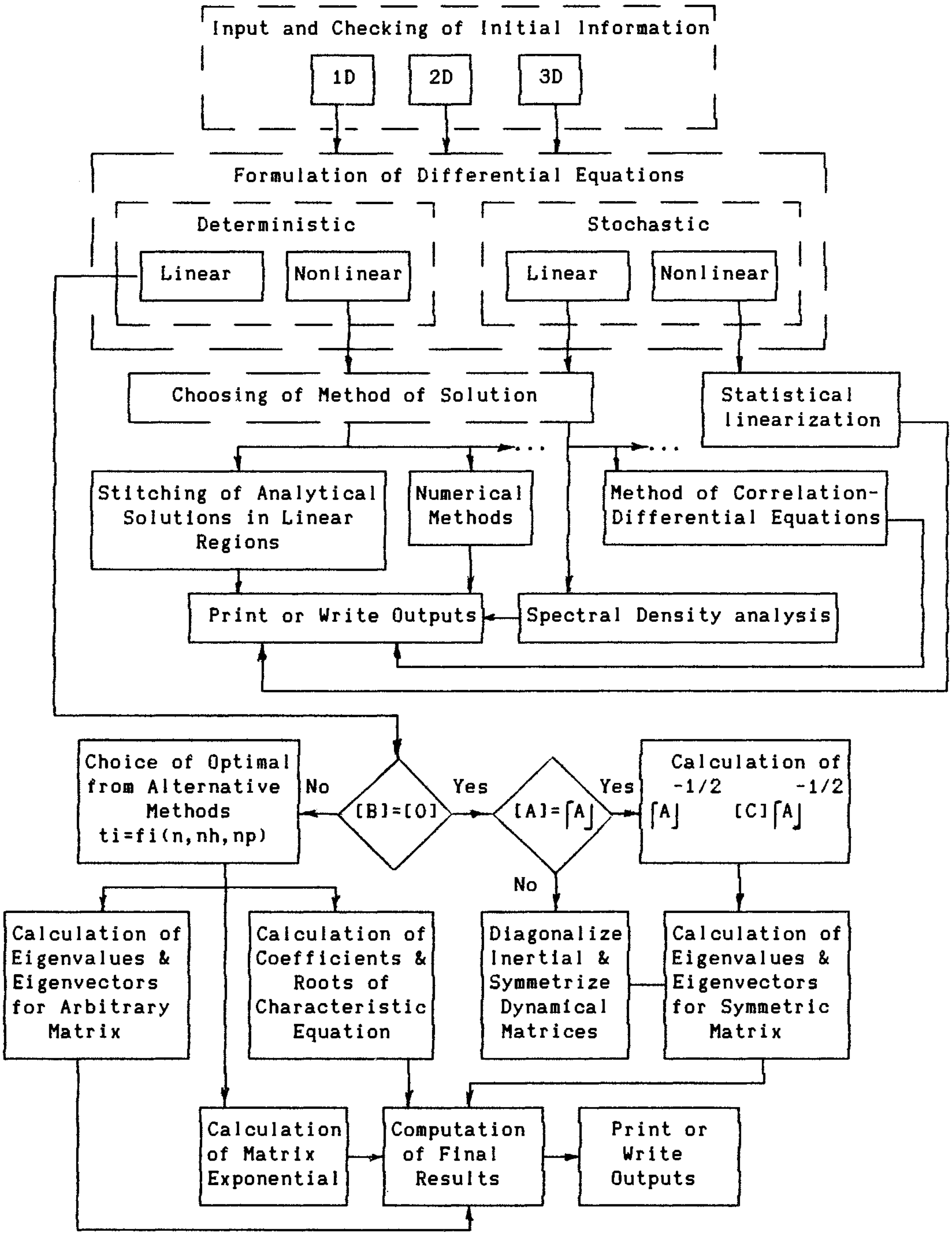

Fig. 2. Simplified functional scheme of IMITA (1D, 2D and 3D - chain, planar and spatial structure; [A], [B] and [C] - inertial, damping and stiffness matrices of linear system; ti -simulation time necessary for i-th method, fi-simple algebraic functions, n - simulated system degrees-of-freedom, nh and np -parameters characterizing the complexity of excitations and outputs; [ ] and ⌈ ⌋ denotes arbitrary and symmetric matrices)

In order to avoid the necessity of a thorough knowledge of the mathematical apparatus of numerical methods for the user, Imita chooses the optimal computation method automatically. The primary system training was carried out by solving with alternative modules the sets of problem tasks that had been chosen in accordance with planned experiment. In further usage Imita trains itself by storing data on the problems to be solved and therefore becomes more and more competent in choosing a solution method. The simple algorithm of method choice for solving linear equations is shown in Fig.2. This aspect also is very important for the time - consuming procedures of synthesis. An appropriate interface to the codes of non-linear programming Supex (ref. 6) and global search Globex (ref. 3) allows to perform various optimization calculations with great efficiency. In this case the user must define the criterion function in a standard form by using screen templates and the menu.

Unified pre- and postprocessors are used for all tools. Descriptions of the objects, tasks and results can be stored in the data base.

Due to dynamic distribution of on-line storage necessary for the software the maximal size of the task is restricted only by the computer resources. Nevertheless, it includes computation methods which are highly effective for objects with up to fifty degrees -of- freedom (D-o-F) and with no more than one hundred parameters of optimization for local and up to thirty for global search. All tools run on IBM and compatible PC under MS-DOS management.

2. Used methods

The quality index functions of dynamical systems are usually multi-extremal, non-analytical and noisy. Due to these peculiarities nonlinear programming methods are practically usable only for narrow search regions. Therefore global search methods based on theories of planned experiments and euristical self - organization are used frequently. Let us consider some ideas underlying of the automatical search algorithm of Globex. Depending on the search results some prospective subregions are singled out of the initial region. The probability of an extreme situation is assumed to be higher in those subregions where function is of a better value as well as in those in which there is a larger number of better points. During search these regions compete mutually.The tactics for locating the extremes in subregions are determined by appropriate coefficients. For example, the parallelepiped reduction coefficient is of the form: $r=a^{m-1}m^{b/d}$, where m is the number of support points (simultaneosly analyzed better points in the respective subregion of a current series of experiments), d is the number of search region dimensions, a and b are constants whose values are obtained from solving sets of appropriate optimization tasks for algorithm training. Finding of extreme is accomplished when, within a given precision, all the subregions have been localized, i.e., when actually the entire summary region is converged in point. The extremes found are isolated from further searching by means of penalty parallelepipeds .

The algorithm of Disint for model synthesis is based on rational singling out of elementary functions from the set of bank functions. The model is obtained as a sum of functions so selected that by the given criteria it simultaneously satisfies all the experimental time realizations in the best way.

The simulation system Imita incorporates both conventional integration and power spectral density methods, and the less frequently employed methods of investigation M-D-o-F systems, namely, those of statistical linearization, of stitching analytical solutions in linear regions, etc., as well as original methods. Let one of them be considered. For determining the statistical characteristics of a linear M-D-o-F system one has to solve two differential correlation equations (ref. 7):

$$[A][\ddot{K}_{qf}(\tau)]+[B][\dot{K}_{qf}(\tau)]+[C][K_{qf}(\tau)]=[K_{ff}(\tau)]$$
$$[A][\ddot{K}^{T}_{qq}(\sigma)]+[B][\dot{K}^{T}_{qq}(\sigma)]+[C][K^{T}_{qq}(\sigma)]=[K^{T}_{qf}(\sigma)] \quad (1)$$

where [A], [B],[C] are inertial, damping and stiffness matrices of order n,

$[K_{ff}(\tau)]$, $[K_{qq}(\tau)]$ are square matrices of correlation functions of excitations {f} and generalised coordinates {q} respectively,
$[K_{qf}(\tau)]$ is a square matrix of mutual correlation function of the column vectors {q} and {f},
τ is the difference of time instants for which the correlation bonds are evaluated ($\sigma=-\tau$),
the sign "T" designates transposition and "." stands for differentiation.

Suppose that the correlation functions of stationary and stationarily bonded random excitations could be approximated by means of expressions of the following type:

$$K_f(\tau)=De^{-\alpha|\tau|}(\cos\beta\tau+\alpha/\beta\sin\beta|\tau|) \quad (2)$$

where parameters D>0, $\alpha>0$, $\beta\geq0$.
The presence of expressions like (2) in the right - hand part of the first correlation equation (FCE) requires its solution to be obtained in two intervals: I1- for $-\infty\leq\tau\leq 0$ and I2- for $0\leq\tau\leq\infty$ with subsequent stitching for argument value $\tau=0$.

The following boundary conditions derive from the properties of the correlation functions:

$$[K_{qf}(-\infty)]=[K_{qf}(\infty)]=[0] \quad (3)$$

The solution of FCE can be obtained in the form:

$$[K_{qf}(\tau)]=[K_{qfc}(\tau)]+[K_{qfp}(\tau)] \quad (4)$$

where $[K_{qfc}(\tau)]$ and $[K_{qfp}(\tau)]$ are matrices comprising the appropriate complementary functions and particular solutions. In wiev of independence of the $[K_{qf}(\tau)]$ columns, let us consider obtaining only one of them. The l-th column of $[K_{ff}(\tau)]$ in I2 has the form:

$$\{K_{ff}(\tau)\}_l=(\{m_1\}_l\cos\beta\tau+\{m_2\}_l\sin\beta\tau)e^{-\alpha\tau} \quad (5)$$

Then the particular solution is sought for in the form:

$$\{\overset{+}{K}_{qfp}(\tau)\}_l=(\{u_1\}_l\cos\beta\tau+\{u_2\}_l\sin\beta\tau)e^{-\alpha\tau} \quad (6)$$

The column vectors $\{u_1\}_l$ and $\{u_2\}_l$ can be found from equation:

$$[VP]\begin{Bmatrix}u_1\\u_2\end{Bmatrix}_l=\begin{Bmatrix}m_1\\m_2\end{Bmatrix}_l \quad (7)$$

where [VP] is a square matrix of order 2n $[VP]=\begin{bmatrix}[V_{11}] & [V_{12}]\\ [V_{21}] & [V_{22}]\end{bmatrix}$ with square submatrices:

$[V_{11}]=[(\alpha^2-\beta^2)[A]-\alpha[B]+[C]]$, $[V_{22}]=[V_{11}]$,

$[V_{12}]=[\beta[B]-2\alpha[A]]$, $[V_{21}]=-[V_{12}]$.

The l-th column of $[K_{ff}(\tau)]$ in I1 has the form:

$$\{K_{ff}(\tau)\}_l=(\{m_1\}_l\cos\beta\tau+\{-m_2\}_l\sin\beta\tau)e^{\alpha\tau} \quad (8)$$

Then the particular solution is sought for in the form:

$$\{\overset{-}{K}_{qfp}(\tau)\}_l=(\{u'_1\}_l\cos\beta\tau+\{u'_2\}_l\sin\beta\tau)e^{\alpha\tau} \quad (9)$$

The column vectors $\{u'_1\}_l$ and $\{u'_2\}_l$ can be derived from equation:

$$[VM]\left\{\begin{matrix} u'_1 \\ u'_2 \end{matrix}\right\}_l = \left\{\begin{matrix} m_1 \\ -m_2 \end{matrix}\right\} \qquad (10)$$

where [VM] is of a structure similar to [VP], but differs in the submatrices of order n, namely:

$[V_{11}]=[(\alpha^2-\beta^2)[A]+\alpha[B]+[C]]$, $[V_{12}]=[\beta[B]+2\alpha[A]]$.

To obtain the l-th coloumn of $[K_{qfc}(\tau)]$ appropriate homogeneous equation has to be solved. Suppose that $[B]\neq[A]\sum a_b[A^{-1}C]^b$ $(b=0,1,\ldots,m)$, (of course, all that follows is also applicable for systems with the classical distribution of damping), then it is convienent to consider equation of the form:

$$\{\dot{K}_{zf}(\tau)\}_l-[W]\{K_{zf}(\tau)\}_l=\{0\} \qquad (11)$$

where $\{K_{zf}(\tau)\}_l$ is a vector column of order 2n with structure: $\{K_{zf}(\tau)\}_l=\left\{\begin{matrix} \{\dot{K}_{qf}(\tau)\}_l \\ \{K_{qf}(\tau)\}_l \end{matrix}\right\}$

and $[W]=\begin{bmatrix} [-A^{-1}B] & [-A^{-1}C] \\ [I] & [0] \end{bmatrix}$, where [I] and [0] are unit and zero matrices each of order n, but the sign "-1" denotes an inverse matrix. If [W] has 2n simple eigenvalues, namely, 2k complex $(\lambda_j=\mu_j\pm i\nu_j,\ j=1,\ldots,k)$ and k_a real $(\lambda_j=\mu'_j,\ j=1,\ldots,k_a)$, then,after appropriate normation, the eigenvectors can be grouped as follows: [[K][K][S]]+i[[L][-L][0]], where [K] and [L]- 2n x k matrices whose columns are the eigenvectors corresponding to the real and the imaginary parts of the complex eigenvalues respectively; [S] is the 2n x k_a matrix which contains the eigenvectors corresponding to the real eigenvalues; [0] is the 2n x k_a null matrix.

Thereby the solution of (11) will be:

$$\{K_{zf}(\tau)\}_l=([K]\ulcorner e^{\mu\tau}\lrcorner\ulcorner\cos\nu\tau\lrcorner-[L]\ulcorner e^{\mu\tau}\lrcorner\ulcorner\sin\nu\tau\lrcorner)\{a_1\}_l-([L]\ulcorner e^{\mu\tau}\lrcorner\ulcorner\cos\nu\tau\lrcorner-[K]\ulcorner e^{\mu\tau}\lrcorner\ulcorner\sin\nu\tau\lrcorner)\{a_2\}_l++[S]\ulcorner e^{\mu'\tau}\lrcorner\{a_3\}_l \qquad (12)$$

where $\ulcorner e^{\mu\tau}\lrcorner$ is a diagonal matrix of order k, whose nonzero elements are $e^{\mu_j\tau}$ $(j=1,\ldots,k)$ and μ_j are the real part of the complex eigenvalues; $\ulcorner\cos\nu\tau\lrcorner$, $\ulcorner\sin\nu\tau\lrcorner$ are diagonal matrices of order k, the nonzero elements of which are appropriate trigonometric functions;

$\ulcorner e^{\mu'\tau}\lrcorner$ is a diagonal matrix of order k_a, whose nonzero elements are $e^{\mu'_j\tau}$ $(j=1,\ldots,k_a)$ and μ'_j are real eigenvalues;

$\{a_1\}_l$, $\{a_2\}_l$ and $\{a_3\}_l$ are vector columns of order k and k_a respectively.

From stitching at $\tau=0$ the FCE solutions in I1 and I2, l equations can be obtained:

$$[Mo]\left\{\begin{matrix} a_1 \\ a_2 \\ a_3 \end{matrix}\right\}_l=\left\{\begin{matrix} \{{}^-\dot{K}_{qfp}(0)\}_l \\ \{{}^-K_{qfp}(0)\}_l \end{matrix}\right\}-\left\{\begin{matrix} \{{}^+\dot{K}_{qfp}(0)\}_l \\ \{{}^+K_{qfp}(0)\}_l \end{matrix}\right\} \qquad (13)$$

where the modal matrix [Mo]=[[K][-L][S]].

By substituting (6), (7) and their derivatives into (13) we obtain:

$$\left\{\begin{matrix} a_1 \\ a_2 \\ a_3 \end{matrix}\right\}_l=[Mo]^{-1}\left\{\begin{matrix} \{r_{\dot{q}}\}_l \\ \{r_q\}_l \end{matrix}\right\} \qquad (14)$$

where $\{r_{\dot{q}}\}_l$ and $\{r_q\}_l$ are vector columns of order n:

$$\{r_{\dot{q}}\}_l=\{\alpha(\{u'_1\}_l+\{u_1\}_l)+\beta(\{u'_2\}_l-\{u_2\}_l)\}$$
$$\{r_q\}_l=\{\{u'_1\}_l-\{u_1\}_l\} \qquad (15)$$

Now the complementary function of FCE assumes the form:

$$\{K_{zf}(\tau)\}_l=([Co]\ulcorner\cos\nu\tau\lrcorner+[Sn]\ulcorner\sin\nu\tau\lrcorner)\{e^{\mu\tau}\}++[Ap]\{e^{\mu'\tau}\} \qquad (16)$$

where $[Co]=[K]\ulcorner a_1\lrcorner-[L]\ulcorner a_2\lrcorner$, $[Sn]=[K]\ulcorner a_2\lrcorner$, $[Ap]=[S]\ulcorner a_3\lrcorner$ and $\ulcorner a_1\lrcorner$, $\ulcorner a_2\lrcorner$, $\ulcorner a_3\lrcorner$ are diagonal matrices, the nonzero elements of which are the appropriate elements of column vectors $\{a_1\}$, $\{a_2\}$, $\{a_3\}$; $\{e^{\mu\tau}\}$ and $\{e^{\mu'\tau}\}$ are column vectors whose elements are appropriate nonzero elements of $\ulcorner e^{\mu\tau}\lrcorner$ and $\ulcorner e^{\mu'\tau}\lrcorner$.

After changing the argument, the second correlation equation (SCE) assumes the form:

$$[A][\ddot{K}_{qq}(\tau)]^T-[B][\dot{K}_{qq}(\tau)]^T+[C][K_{qq}(\tau)]^T=[K_{qf}(\tau)]^T \qquad (17)$$

For practical purposes it is sufficient only to obtain the particular solution of (17) for $\tau\geq0$:

$$[K_{qqp}(\tau)]^T=[K_{qq1}(\tau)]^T+[K_{qq2}(\tau)]^T \qquad (18)$$

where $[K_{qq1}(\tau)]^T$ and $[K_{qq2}(\tau)]^T$ comprise solutions of (17) when in the right - hand of (17) there are: 1)the particular solution of FCE and 2) the complementary function of FCE - both in I2. In wiev of independence of the $[K_{qq}(\tau)]^T$columns, let us consider obtaining only one of them. If the l-th column of $[K_{qf}(\tau)]^T$ for $\tau\geq0$ has a shape similar to that of (6) then the particular solution can be found in the form:

$$\{K_{qq}(\tau)\}_l=(\{s_1\}_l\cos\beta\tau+\{s_2\}_l\sin\beta\tau)e^{-\alpha\tau} \qquad (19)$$

The column vectors $\{s_1\}_l$ and $\{s_2\}_l$ can be derived from equation:

$$[VM]\left\{\begin{matrix} s_1 \\ -s_2 \end{matrix}\right\}_l=\left\{\begin{matrix} u_1 \\ -u_2 \end{matrix}\right\}_l \qquad (20)$$

where [VM] is the above - considered square matrix of order 2n.

Since the expressions for the FCE complementary function (16) are of a structure similar to that the elements of $[K_{qfp}(\tau)]$, likewise $[K_{qq2}(\tau)]$ can be obtained. Thus, for obtaining of $[K_{qq2}(\tau)]$ one has to inverse n matrices of the type [VM]. Thereupon the necessary dispersion matrices of the output processes can be obtained, for example, of generalized coordinates $[D_{qq}]=[K_{qqp}(0)]$.

The developed method is somewhat cumbersome but from the computational point of view, in many cases, it proves more efficient than the spectral density analysis. To sum up, it requires solving the standard eigenvalue problem for an arbitrary real matrix of order 2n and inverting (n+3) times of matrices of order 2n as well as perfomance of several simple operations.

3. Some examples

3.1. Optimization of lorry suspension.

In order to reduce harmful vibrations caused to vehicles by the unevenness of roadways, suspensions are used with either passive or else with more effective active control involving greater expenses. The former are frequently used for improving the dynamical characteristics of convential heavy trucks.

Let us consider the results of optimizing the rear suspension for the lorry STAR-200 (Poland). The lorry model (ref. 8) consists of three bodies connected by elastic and damping links with nonlinear characteristics. These characteristics were approximated in piece - linear form. Also it is assumed that in the case of a constant speed of the vehicle the excitations caused by the unevenness of the roads are ergodic stationary Gaussian processes, which can be described in terms of appropriate spectral densities or correlation functions. Statistical modelling was used for the determining the lorry behaviour. For this, polyharmonic series are first generated from the catalogued spectral densities. As frequency analysis shows, it is sufficient only to consider 10-20 members of series depending on the road type and velocity of the vehicle. Integration was carried out by means of the stitching method which in essence consists in searching for the instants of switches from one linear state to another. For this it suffices just once to find by computer the analytical solutions, which can then be immediately used whenever the states recur. Optimization of the rear suspension spring force is achieved by minimizing the following quality index:

$$Cr=\sum_{k=1}^{NW} \rho_k \Big(\sum_{j=1}^{NL} \lambda_j \Big(\sum_{i=1}^{N} \big((\overset{-}{\ddot{x}}_i)^2 + (\overset{+}{\ddot{x}}_i)^2 \big)/N \Big)\Big) \quad (21)$$

where ρ and λ are the coefficients of the road types and truck loads used; $NW=4$ and $NL=3$ are the numbers of the road types and the states of the truck load, respectively; N, $\overset{+}{\ddot{x}}_i$ and $\overset{-}{\ddot{x}}_i$ are the number of the typical points of the lorry, the maximal and minimal values of the acceleration at these points.

At the same time restrictions are to be satisfied: 1) on vertical acceleration and 2) on the suspension deformation.

Five parameters were optimized: 1) three coefficients of stiffness on the linear spans and 2) two coordinates of splits of the spring characteristic. Functions like (21) are noisy and have many extremes. Therefore the global search method was used. The obtained characteristics of the rear suspension spring force are shown in Fig. 3 for the case of lorry exploitation conditions given in Table 1 (unevenness of all the roads are described by such spectral densities $S(\Omega)=D(\Omega)^{-u}$ $[m^3/rad]$, where $\Omega=\omega/V$, V is the velocity, L is the basic wave length, σ is the standard deviation). The values of the parameters of the obtained global extreme are: c_1=630 kN/m, c_2=1015, c_3=28323 kN/m and Δ_1=0.006 m, Δ_2=0.12 m and criterion Cr=24.0. Utilization of characteristic γ (Fig. 3) reduces the accelerations of the lorry from 24% to 2% and decreases deformation of the suspension by 30% in comparison with the natural STAR-200. A final decision could be made only after a series of optimizations in accordance with different criteria applied and has certainly to be based on experts' opinion.

3.2 Crumbling machine.

Optimizing the dynamics of technological machines (ref. 9) is very important, especially in the early stages of designing when the designer has to make fundamental decisions. More simply than in the previous example, let us consider the task of optimizaing a crumbling machine (Fig. 4) consisting of a body m_1 on which there is situated a vibrator, a whacking body m_2 and an anvil body m_3. Each of the rigid bodies is assumed to have one D-o-F and linear links. A harmonic force $f(t)=F\cos\omega t$, which is independent of the system motion, acts on body m_1. As identification in the first degree of approximation shows, impact energy is only expended on the technological process of crumbling, but the impact is characterized by two independent random quantities, namely, e which is the coefficient of restitution in accordance with the triangular law and δ - the layer of the crumbled material, which obeys the rectangular law. The values of both e and δ vary from impact to impact ±0.5 of their nominal values. The quality index is power N, which is lost by the system in the impact processes of the quasistationary vibrations. The optimization parameters and the initial regions of search are supplied in Table 2.

Table 2. Initial regions of search

Parame- ters of optimi- zation		Di men si on	Values of boundaries of parameters variation regions in experiment No 1	2	3	4
1 ω	min	1/s	70.	70.	70.	70.
	max		200.	200.	200.	200.
2 m_2	min	10^3kg	0.01	0.01	0.01	0.01
	max		2.	2.	2.	2.
3 $\frac{m_3}{m_2}$	min	-	1.	1.	1.	1.
	max		10.	10.	10.	10.
4 c_0	min	kN/m	1000.	1000.	1000.	1000.
	max		10000.	10000.	10000.	10000.
5 Δ	min	m	0.001	0.001	0.001	0.01
	max		0.1	0.1	0.1	0.01
6 F	min	kN	100.	100.	50.	50.
	max		2000.	1000.	500.	50.
7 m_1	min	10^3kg	0.2	0.2	0.2	0.2
	max		16.	16.	6.	6.
8 c_2	min	kN/m	100.	100.	100.	100.
	max		10000.	10000.	10000.	10000.

Table 1. Parameters characterizing the exploitation conditions of the lorry

Road type	D	u	σ	V	L	ρ	λ for loads [kN] 0	30	60
Asphalt	$5.782\ 10^{-6}$	2.08	$8.0\ 10^{-3}$	19.444	40.	0.75	0.2	0.5	0.3
Pavement	$30.057\ 10^{-6}$	1.54	$13.5\ 10^{-3}$	11.111	40.	0.15	0.2	0.5	0.3
Country	$3.160\ 10^{-4}$	2.	$39.0\ 10^{-3}$	5.555	20.	0.06	0.2	0.5	0.3
Terrain	$1.\ 10^{-3}$	2.	$70.0\ 10^{-3}$	2.777	20.	0.04	0.2	0.5	0.3

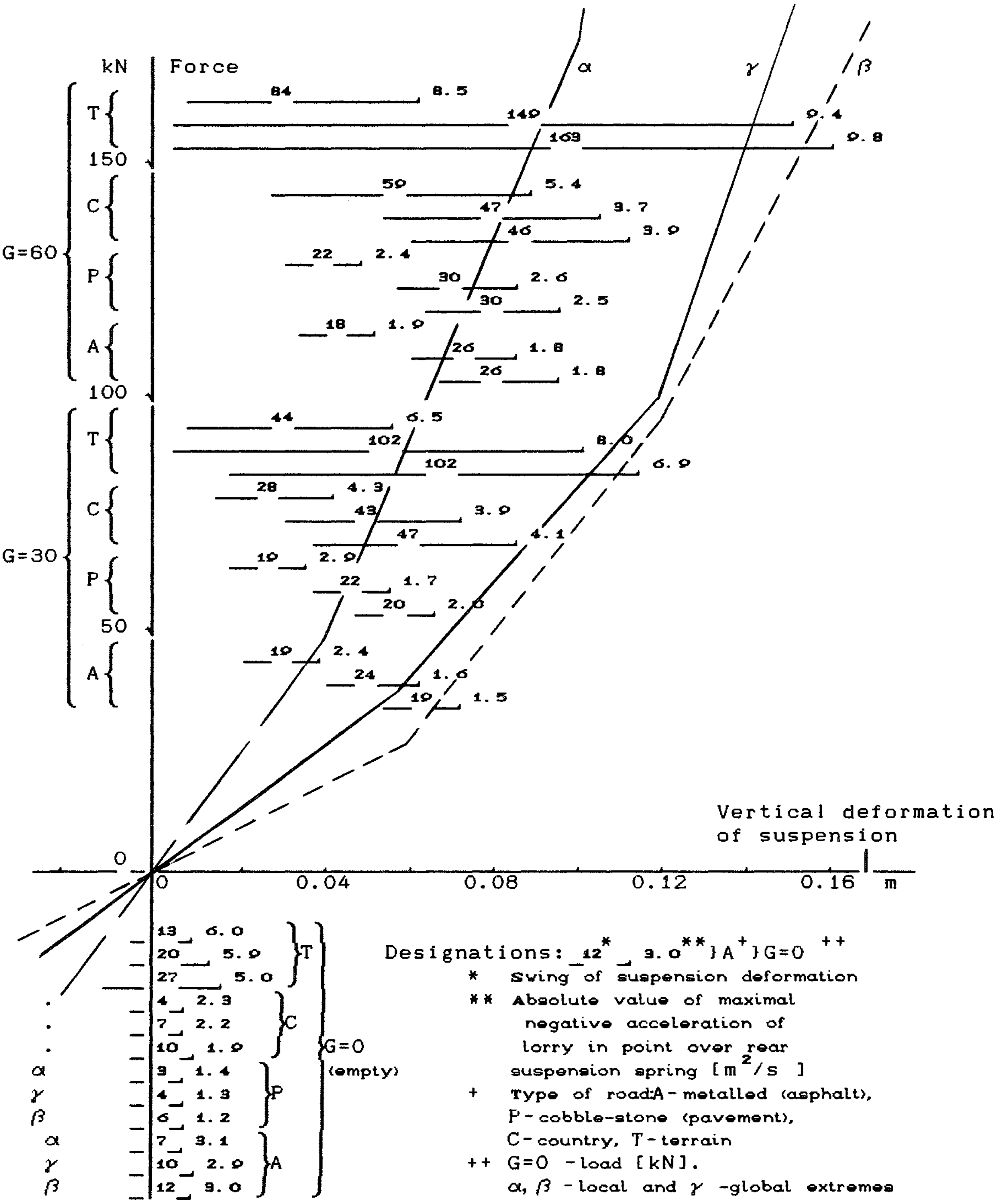

Fig. 3. Schematic diagram of suspension spring force

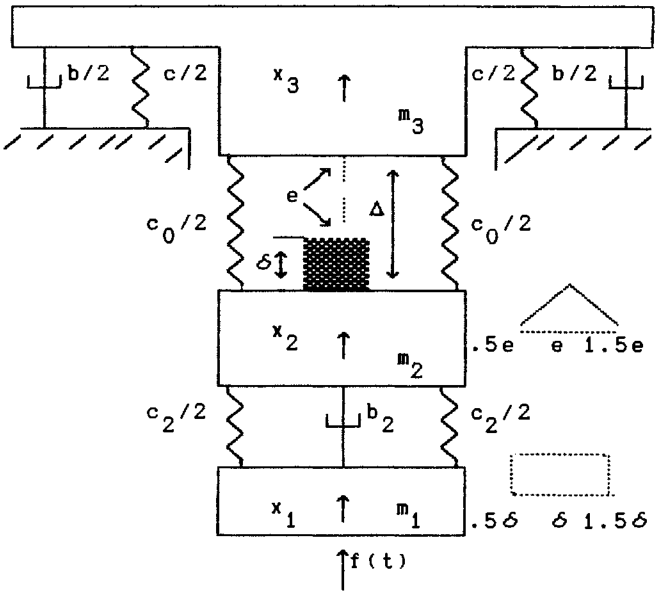

Fig. 4. Dynamical scheme of a crumbling machine

The values of non-variable parameters are: c=100 kN/m, $b=b_2=2$ kN s/m. Due to broad variation regions in the first optimization experiments e and δ are constant, i.e., e=0.1, δ=0. After execution of 540 trial points the first extreme was obtained. As it is seen from Table 3, the mass of body m_1 and frequency ω drag to their lower boundaries, but the amplitude of the excitation force F, split Δ, masses m_2 and m_3 tend to their upper boundaries. In view of the great acceleration of body m_1 let us deminish the upper boundary of F two times. In the second experiment F drags to its upper boundary again

Table 3. Results of the optimization experiments

Para-meter	Di-men-si-on	Values of the parameters obtained in experiment No. 1	2	3	4
1 ω	1/s	70.	70.9	72.4	72.
2 m	10^3kg	1.87	1.99	1.7	1.8
3 $\frac{m_3}{m_2}$	-	9.9	9.9	2.0	2.5
4 c_0	kN/m	9614.	6387.	4718.	5973.
5 Δ	m	0.097	0.0985	0.0037	0.01
6 F	kN	1994.	1000.	52.6	50.
7 m_1	10^3kg	0.21	0.25	0.22	0.23
8 c_2	kN/m	1094.	1297.	1200.	1383.
E	kJ	11400.	5094.	13.5	12.1
N	kW	128.10^3	$57.6\ 10^3$	156.	139.
Cr	-	-128.10^3	$-57.6\ 10^3$	107.	-139.

and the other values of parameters are similar to those obtained in experiment No.1. However, the acceleration swing of body m_1 is greater than the permissible one. At the same time we can make simple conclusion: for higher N is needed greater F. The third experiment is implemented for the complex criteria with penalty depending on acceleration of body m_1. It has yielded results according to which the amplitude of force F and the mass of body m_1 reach their lower bounds but the mass of the body m_2 remains maximal as before. At the same time oscillation swings are not great and the acceleration law for body m_1 virtually represents a harmonic, i.e. there is no impact load upon the vibrators.

All the optima obtained are characterized by modes under which there is one impact of bodies per one extitation period and this testifies the energetic advantages of such modes. Although, in general, the power characteristics are the better, the more intensive the process is, yet no tendency revealed itself towards high frequences. To clarify the situation, let us examine Table 4, which presents the eigenvalues $\lambda_j=-\mu_j \pm i\nu_j$ of the system and relations of its imaginary parts to the excitation frequency. It turns out that one of the basic features of an extremity is the fact of proximity of the excitation frequency to the eigenfrequency caused by the mass of body m_2.

Now a fourth optimization experiment has been conducted with randomly varyied parameters e and δ, the nominal values being e=0.1 and $\delta=0.3\Delta$ and the F and Δ being fixed. The obtained criteria value decreased to ~ 11%, the main tendency of the optimizing parameter behaviour was retained.

By means of the developed software it is easy to obtain sections of the criterion functions, by varying any parameters in the ranges of interest. In this particular case, the system proved to be sensitive to the changes of parameter b_2.

Table 4. Eigenvalues of the system linear part

No.	Para-meter	Number of the extreme 1	2	3	4
1	ω	70.	70.9	72.4	72.
2	μ_1	3.53	6.4	4.55	4.31
3	ν_1	86.	199.	82.7	87.16
4	μ_2	1.76	2.6	0.69	0.66
5	ν_2	63.4	65.4	58.8	61.7
6	μ_3	0.049	0.05	0.19	0.15
7	ν_3	2.2	2.2	4.3	3.9
8	ν_1/ω	1.23	2.8	1.14	1.21
9	ν_2/ω	0.905	0.92	0.81	0.86
10	ν_3/ω	0.03	0.03	0.059	0.054

3.3. Mobile complex of equipment for manufacturing of concrete articles.
Investigations into the dynamics of technological machines for moulding concrete articles provide ways of developing original equipment for automated manufacture of building blocks, slabs,kerbs etc. The production technology is based on the method (ref. 10) of double - sided vibro - impact pressing of the items.It allows to rise an item's grade 2 - 2.5 times and at the same time to diminish the astringents consumption to 25%. There are two main modifications of production sections- stationary and mobile both with an annual output of 10.000 m^3.The heart of the equipment is a vibro - moulding rotary automatic machine with a horizontal axis of rotation (see Fig. 5). It performs six technological operations simultaneosly: 1) filling, dosage and vibro - consolidation of moist concrete mixture in a matrix; 2) moulding by means of the opposite vibro- impact pressing; 3) density check - up by means of the non - contact method; 4) taking out the finished items; 5) cleaning and 6) lubricating of the mould - matrices. The installation is so designed as to make it possible to diminish the area of manufacturing 4 - 5 times and increases productivity in comparison with similar purpose installations 4 - 5 times. The hydraulic double sided vibrator is the main component of an automatic machine. It provides a special law of form motion and specific pressure on the moulded items not less than 1.5 MPa, i.e. the possibility to widely use dry concrete mixtures. The design of the vibrator prevents the vibration from affecting the rest of the construction and the environment.

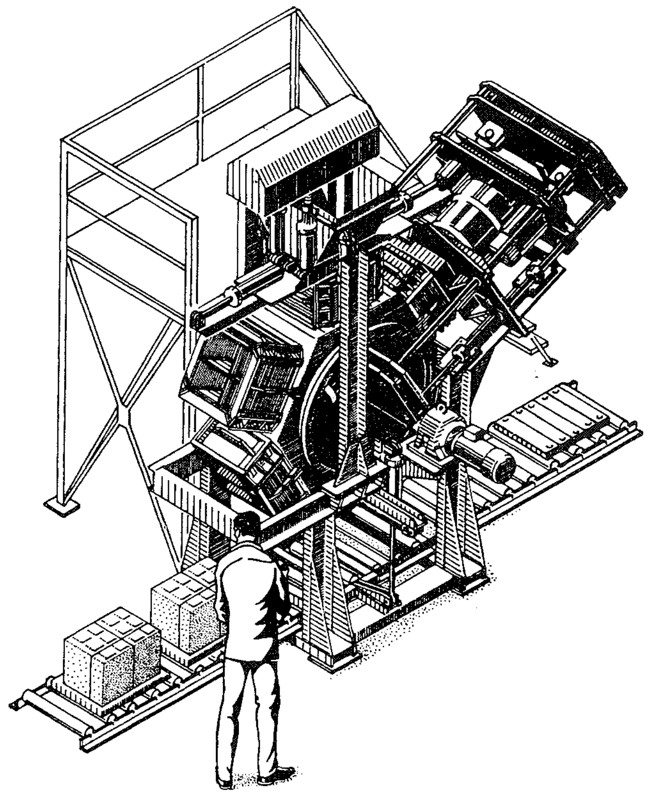

Fig. 5. Vibro-moulding rotary automatic machine

The possibility of changing the depth of forms - matrices allows to get the same height of building blocks regardless of the range of the employed fillings (sawdust, shavings, dolomite siftings, slags and other industrial waste). A quick readjusment is provided to produce items of varios nomenclature. The mobile complex needs no more than two people to operate it.

CONCLUSIONS

Applications software has been developed for automation of dynamic calculations concerned with identification, simulation and optimization of mechanical systems. It consists of convienent engineer oriented tools for synthesis of transient and stationary behaviour of systems composed of rigid bodies connected by means of non-inertial elastic and damping links with arbitrary non- linear characteristics and subjected to deterministic or stochastic excitations.
The developed software is succesfully applied in investigating various mechanical objects, vehicles including. The obtained recommendations are utilized for essential improvements of the dynamical characteristics of real industry objects. At the same time the expenses involved are relatively low. As practice has shown, when working with the proposed codes, the user needs to do only a few hours for preliminary training.

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