INJECT Software

User Manual

Version 4.252

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About

This software simulates fuel delivery processes in fuel injection systems and it can be used in R&D projects to analyze, design, calculate and optimize fuel systems.

Developmenthasbeenstartedat 1984. The first version was founded on Fortran-4 code and used punched cards as data source.

Since 1986 this software uses Fortran-77 program code and it is possible to use dialogue mode.

In 1990 it is used in educational process in Bauman Moscow State Technical University. Students of 6^{th} grade and last year Magister degree students use this software for their projects.

In 1993 the graphic shell has been developed. It was used in DOS OS and then in OS Windows up to 97.

In 2009, the new improved fourth version of this software has been released. It is compatible with OS Windows-NT, XP, Vista, 7 and 8. Interface is fully reworked to meet modern usability requirements.

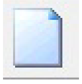
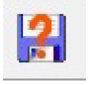
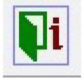
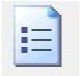
User can choose different fuel system types and adjust them by disabling some elements and by specifying of others parameters.

More than 30 years this software is being used and developed both interface and math models are being improved.

System requirements:

- Pentium CPU or higher.
- SVGA graphics or higher.
- Windows XP or higher.
- 50 Mb free disc space.
- 100 Kb free disc space for each project.

Hotkeys actions:

	New Project
	Open Project
	Save Project
	Save Project As
	Operational Conditions and Calculation Mode
	Control Valve Electric Drive
	Output Data
	Scanning
	Run
	Computing Protocol
	Integral Characteristics
	2D Plot: Instant Characteristics
	2D Plot: Integral Characteristics
	3D Plot

[File] menu

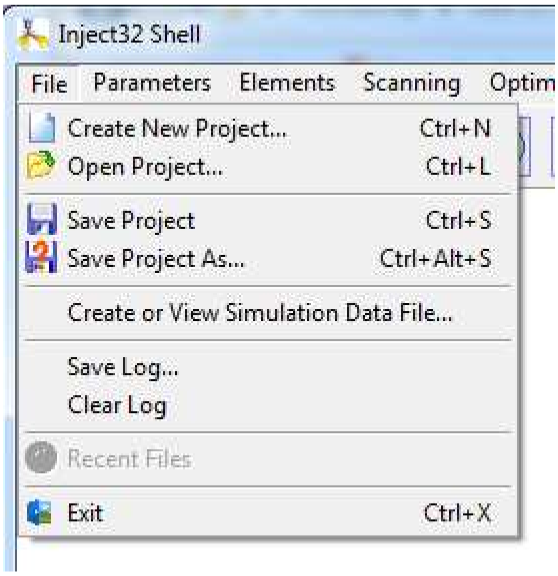


Fig. 1 – [File] menu

In this menu, you can create, open or save the project. The following options are presented:

- **Create new project** – Create new project and select fuel system scheme.
- **Openproject** – Load existing project from data file.
- **Saveproject** – Save current project to the same directory.
- **Saveprojectas** – Save current project to another directory.
- **Create or view simulation data file** – View data file with calculation results.
- **Savelog**– Save all output text data to file.
- **Clearlog**– Clear output field.
- **Exit**– Finish current work session.

Select fuel system type

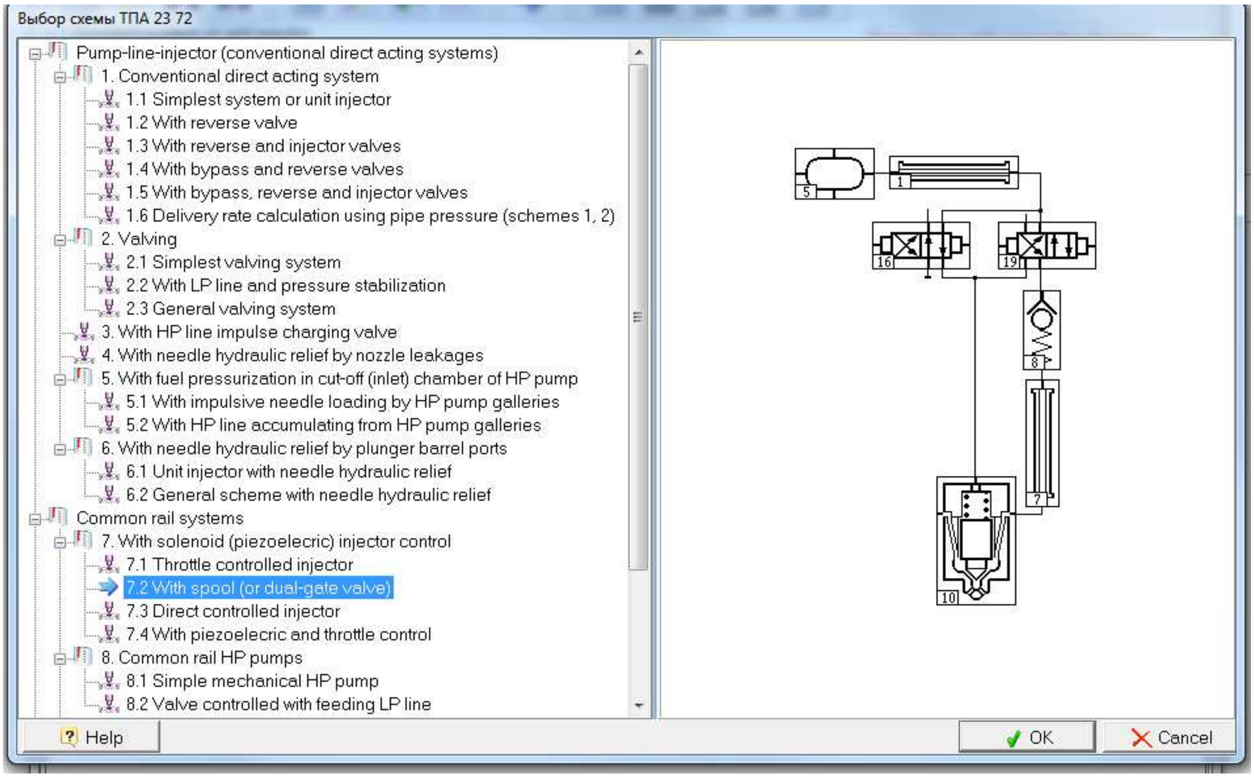


Fig. 2

When you create new project, the window with selection of fuel system type will been shown. Depending on selected scheme, some data fields will been filled using generic values.

[Parameters] menu

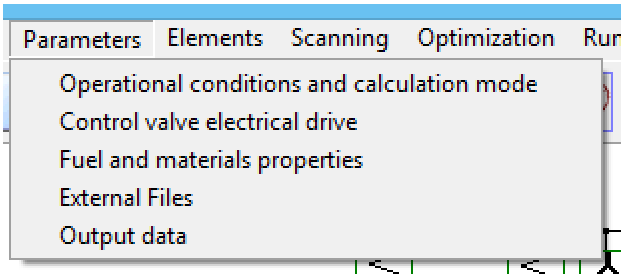


Fig. 3 – [Parameters]menu

Inthismenu(fig. 3)youcansetthegeneralinputdata.Each menu element opens a table or sub-menu with thedata, which you can edit.

Themostfrequentlyuseditems[Operational conditions…], [Control valve electrical drive]and[Output data] have hotkeys duplicating menu items.

[Operational conditions and calculation mode] menu

 - hotkey picture.

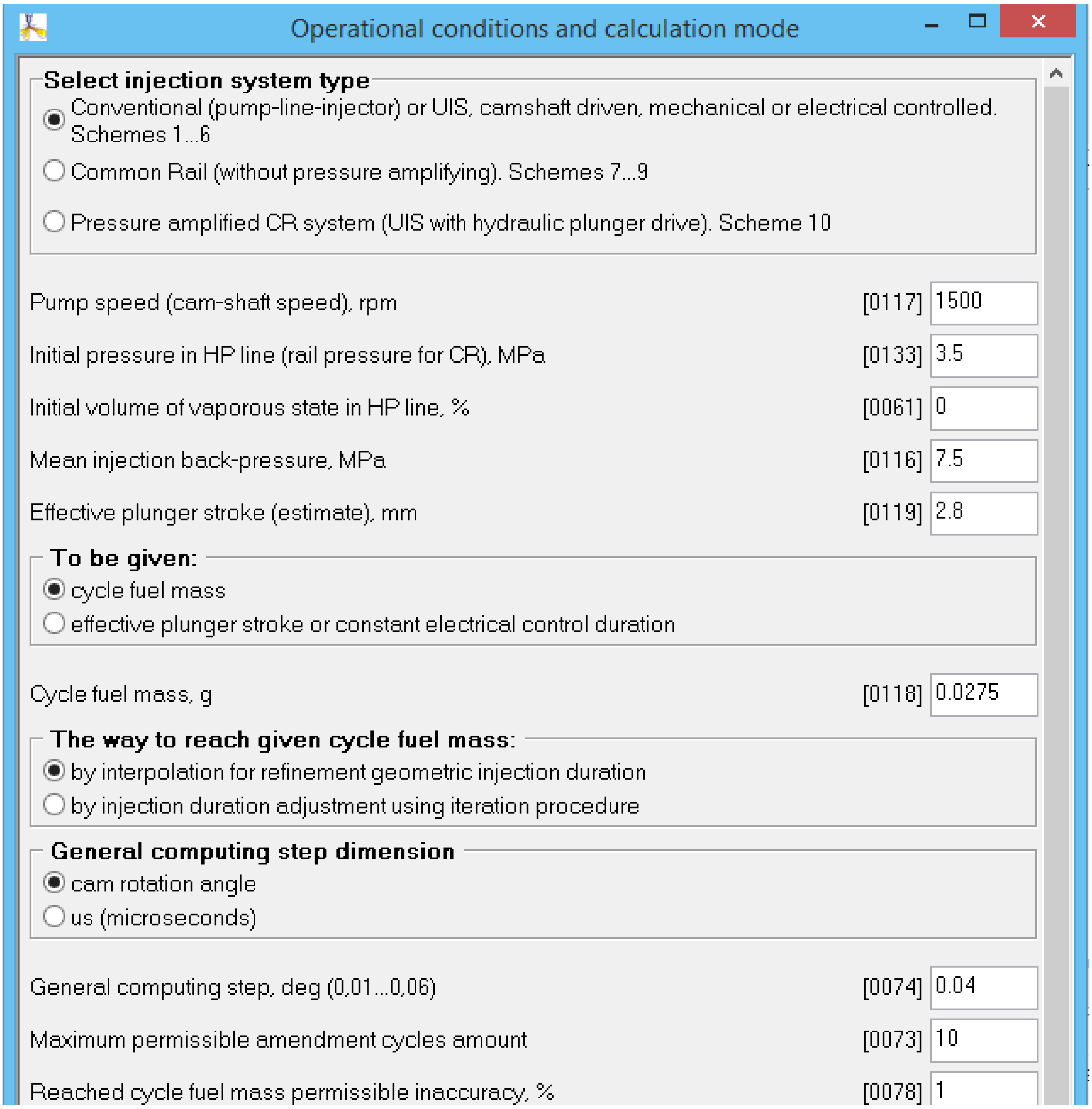


Fig.4 – [Operationalconditions…] menu

Inthisform (fig. 4)you can specify the general information about the fuel injection system:

- **Pumpspeed**(camshaft speed if HP pump is not presented in current system), rpm – [117]

- **Mean injection back-pressure**, MPa – [116]
- **Initial pressure in HP lime** (rail pressure for CR), MPa – [133]. In CR systems this value should be equal to rail pressure ([076] parameter in [HP accumulator or drain] element). If it is not equal program will correct data automatically and will show warning.
- **Initial volume of vaporous state in HP line**, % - [061]
- **Effective plunger stroke**$h_{pl.\ act.}$, mm – [119]

Then you should choose to use cycle fuel mass or effective plunger stroke or electrical control duration as computational goal:

- Cyclefuelmass [118]. In this case you can choose also interpolation for geometric injection duration refinement or injection duration adjustment using iteration procedure as the way to reach given cycle mass.
- Effective plunger stroke [119].

Itispossibletoselectdimensionofgeneralcomputingstep: cam rotation angle or microseconds (us). ThesecondoptionisactualforCRsystems.

Generalcomputingstep [074] isspecifiedinselectedunitswithinthe0.01…0.06 degor5…10 us. Smallstepsizecausescomputingtimegrowthbutbigstepsize impairs accuracy.**General computing start angle** [071] counts from the beginning of follower lift.

Reachedcyclefuelmasspermissibleerror [078] definesthe difference between specified and reached cycle fuel mass. Recommended 1-2%. **Maximum permissible amendment cycles amount** [073] – number of cycle fuel mass adjustment iterations.It is recommended to set small value to test the system. Biggervalueisneededtoperformrealcalculation.

Normalcalculationfinishisautomaticprogramendingwithcyclesamountlessthanmaximum.

General computing ending condition may be:

- reaching defined cam rotation angle [072]. Ifplungerareafillingparameterswerespecifiedin “drivedynamics” menu then it is recommended to set 360 deg. Forconventionalsystemsitisrecommendedtoset 60-70 deg.Totestafterinjection possibility you can increase this value by 10-15 deg.
- by the end of injection and valves seating (for CR systems at the second cycle).

Aftertheendofinjectionandcompleting ofgeneralcomputingthecomputingwithincreasedstep [075]isperformedtillbeginning of the next cycle.

Debuginformationscreenoutputstep[077] definesoutputthat you can activate by the corresponding checkbox in [Parameters] > [Output data].Itisnotrecommendedto use this option until the program incorrect work diagnosis is needed.

Specifyingofinitialintercycleoscillationsdamping decrement of cycle fuel mass and initial pressure during the process of adjustment [081]is used for acceleration of iterative process convergence during cycle fuel mass adjustment using progressive variable correcting coefficients.Thisvalueisalwaysbetween0and 1. Itisrecommendedtouse 0.6…0.9 for no initial pressure selection and 0.3…0.4 for another option.Decrement progressive gain in intercycle oscillations process [082] it is one more way to adjust process and should be greater than 1 (e.g. 1.1).

Weightingfactorsone-stepmethod is the way to decrease instability of differential equations integration.

Allboundaryequationsarereducedtothe ordinary nonlinear differential systems: $dY/dt = f(t,Y)$. Euler method that is usually used in fuel injection models $Y^{j+1} = Y^{j} + \Delta t \cdot f(t^{j}, Y^{j})$ is conditionally stable. Implicit Euler methodfor systems of equations: $Y^{j+1} = Y^{j} + \Delta t \cdot f(t^{j+1}, Y^{j+1})$.

Weightingfactorsone-stepmethod $0<\sigma<1$:

$$Y^{j+1} = Y^{j} + \Delta t \cdot \sigma \cdot f(t^{j+1}, Y^{j+1}) + \Delta t \cdot (1-\sigma) \cdot f(t^{j}, Y^{j}) .$$

Itisrecommendedtospecify this coefficient [726] as0.33, that releases preceding step priority.

Several initialization modes are available:

- Initialpressureisspecified. No adjustment of initial pressure and residual volume.
- Step-by-step residual and initial pressure (and volumes) adjustment using cumulative mass balance method. Inthisandthefollowingcasesreached initial pressure permissible inaccuracy [739] is specified. It is recommended to set 3 to 4 times greater value than cycle fuel mass permissible inaccuracy.
- Specifying the initial pressure and adjusting pressure over the needle for systems with leakage storing.
- Specifying the initial pressure and adjusting pressure over the needle by HP line pressure averaging method after the ending of general computing.

Itisprovidedtwowaystoanalyzepipefriction: express analysis using average velocity and amended estimate using local velocity that is recommended for long pipes. Also both turbulent and laminar flow models are available to calculate fluid friction in pipes.

Systemprovidefunctionalityfortransient mode calculation correction.

[Control valve electrical drive] menu

 - hotkey picture.

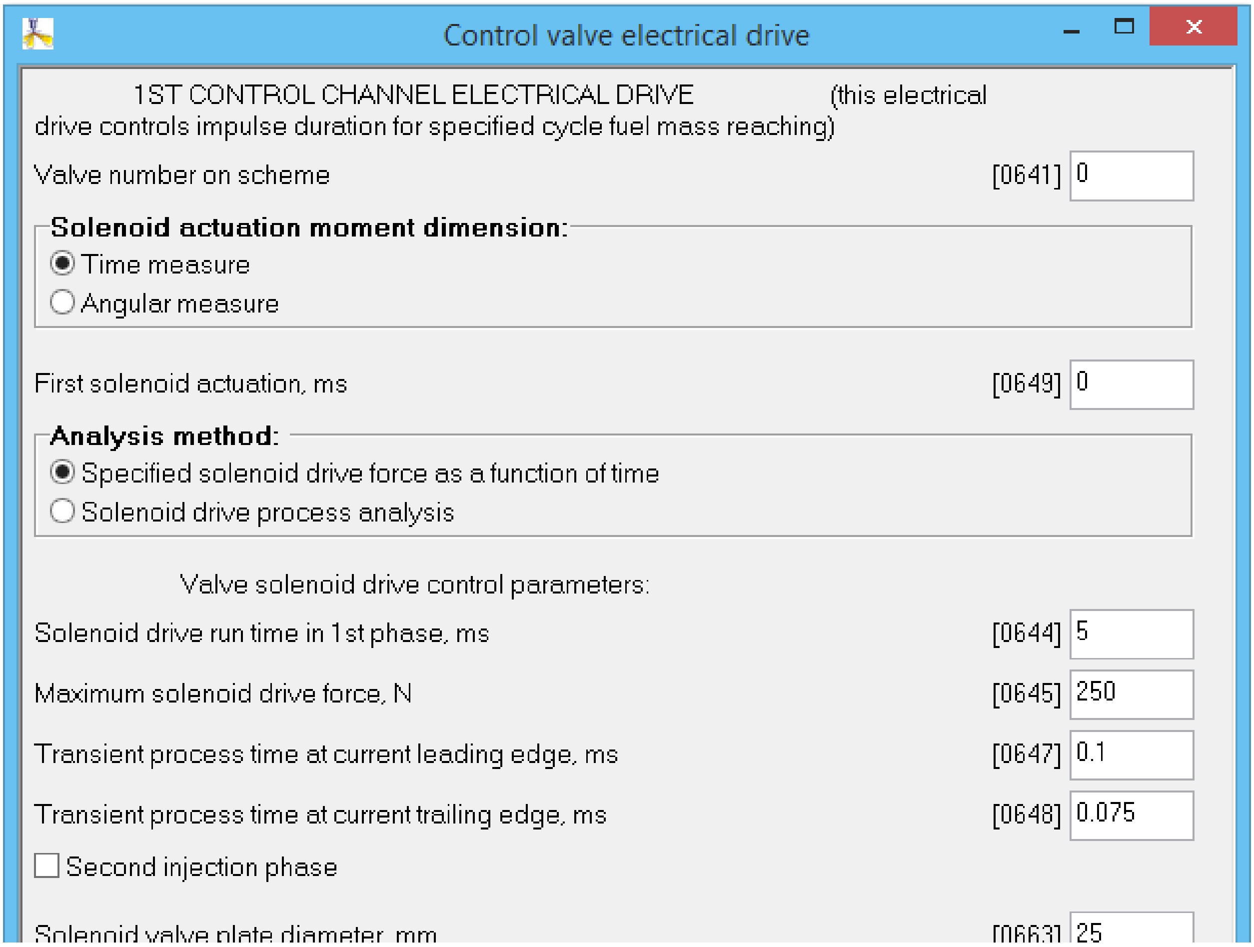


Fig5 – [Control valve electrical drive] menu

Inthismenu(fig. 5) control valve solenoid drive parameters are set corresponding to chosen analysis method:

- Specified solenoid drive force as a function of time.
- Solenoid drive process analysis.

General parameters for first case are shown at fig. 6.

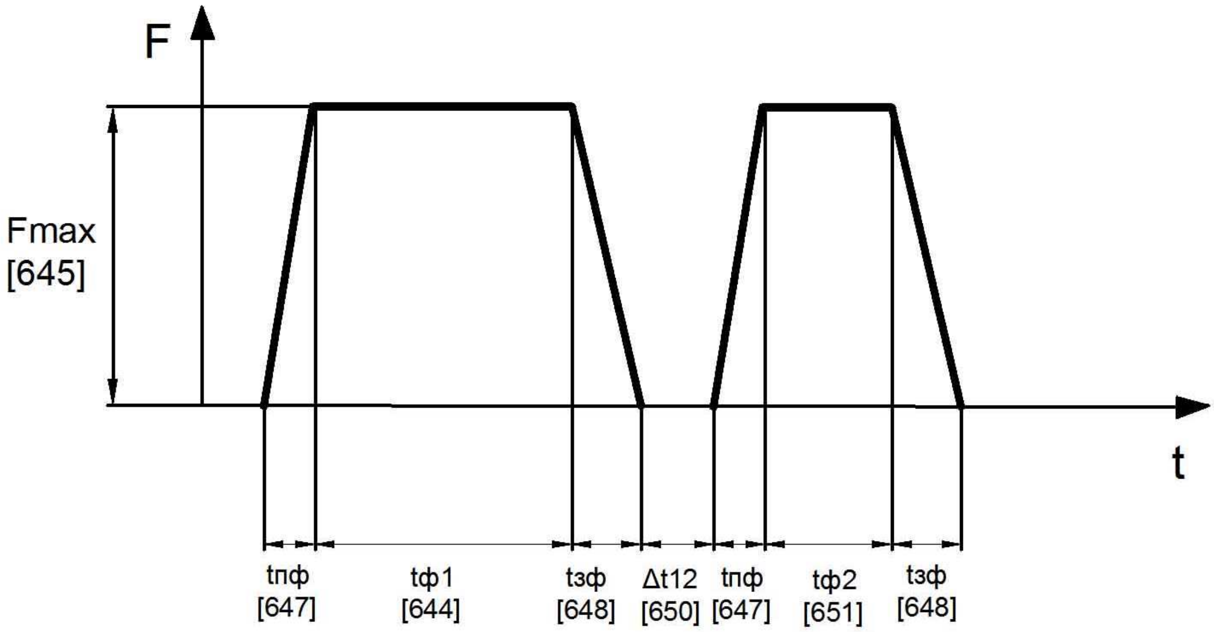


Fig6 – Solenoid control parameters

- **[644]**–Solenoid drive run time in 1st phase, ms
- **[645]**–Maximum solenoid drive force, N
- **[647]**–Transient process time at current leading edge, ms
- **[648] -** Transient process time at current trailing edge, ms
- **[650]**–Interval between 1st and 2nd solenoid actuations, ms
- **[651]**–Solenoid drive time in 2nd phase, ms

It is possible to use both solenoid drive control voltage chart and current chart to define control impulse in simultaneous calculations of electrical, magnetic and hydro mechanical processes in solenoid.Parameters used in calculation depending on definition method are shown at fig. 7 and 8.

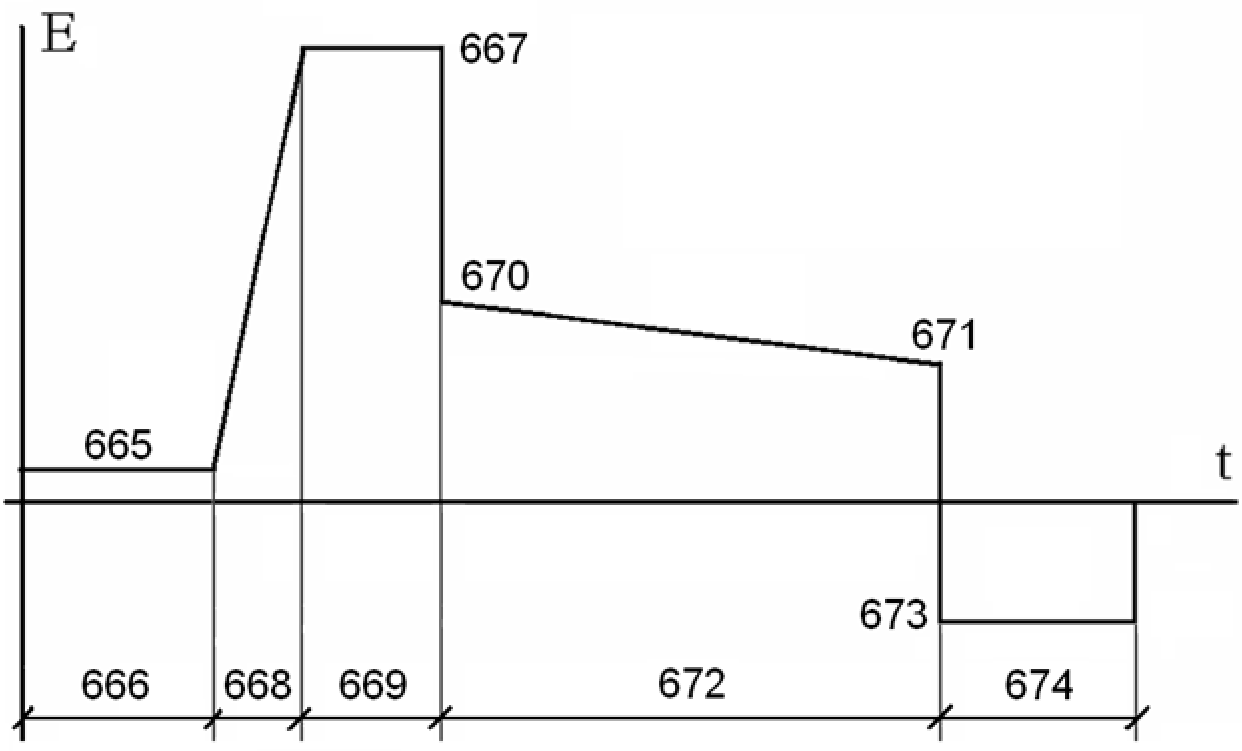


Fig. 7 – Solenoid drive control voltage chart

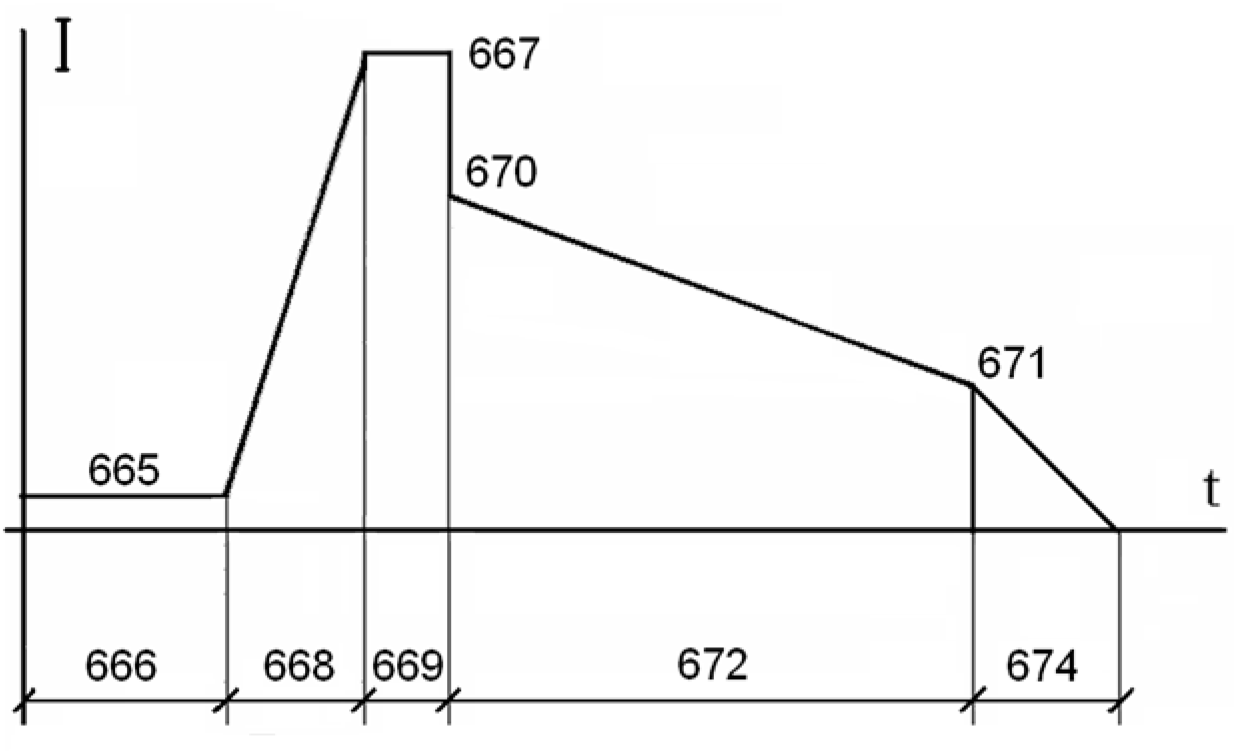


Fig. 8 – Solenoid drive control current chart

- **[665]** – Preliminary segment voltage (before actuation), V
- **[666]** – Preliminary segment duration, ms
- **[667]** – Peak segment booster capacitor voltage, V
- **[668]** – Current rise at the leading edge (to the max), ms
- **[669]**–Peak current segment duration, ms
- **[670]** – Voltage at the beginning of holding segment, V
- **[671]** – Voltage at the end of holding segment, V
- **[672]** – Holding segment duration (produces an effect on cycle fuel mass), ms
- **[673]** –Demagnetizing voltage (negative sign), V
- **[674]** –Demagnetizing duration, ms

Electrical circuit is shown at fig. 9.

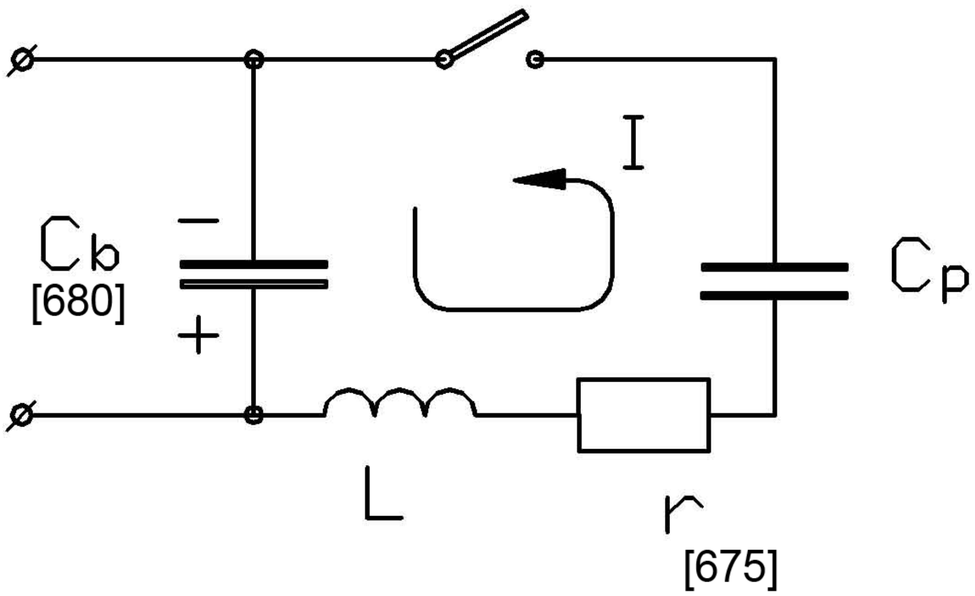


Fig. 9 – Electrical circuit parameters

- **[680]** – Booster capacitor capacity, mF
- **[675]** – Active resistance of full external circuit (without coil), Ohm

* **[702]** – Weighting factors one-step method coefficient for integral stability in solenoid drive analysis (recommended value – 0.33: preceding step priority). More information about this method you can find in chapter*[Parameters]>[Operational conditions and calculation mode]…*

Solenoid parameters are shown at fig. 10 below.

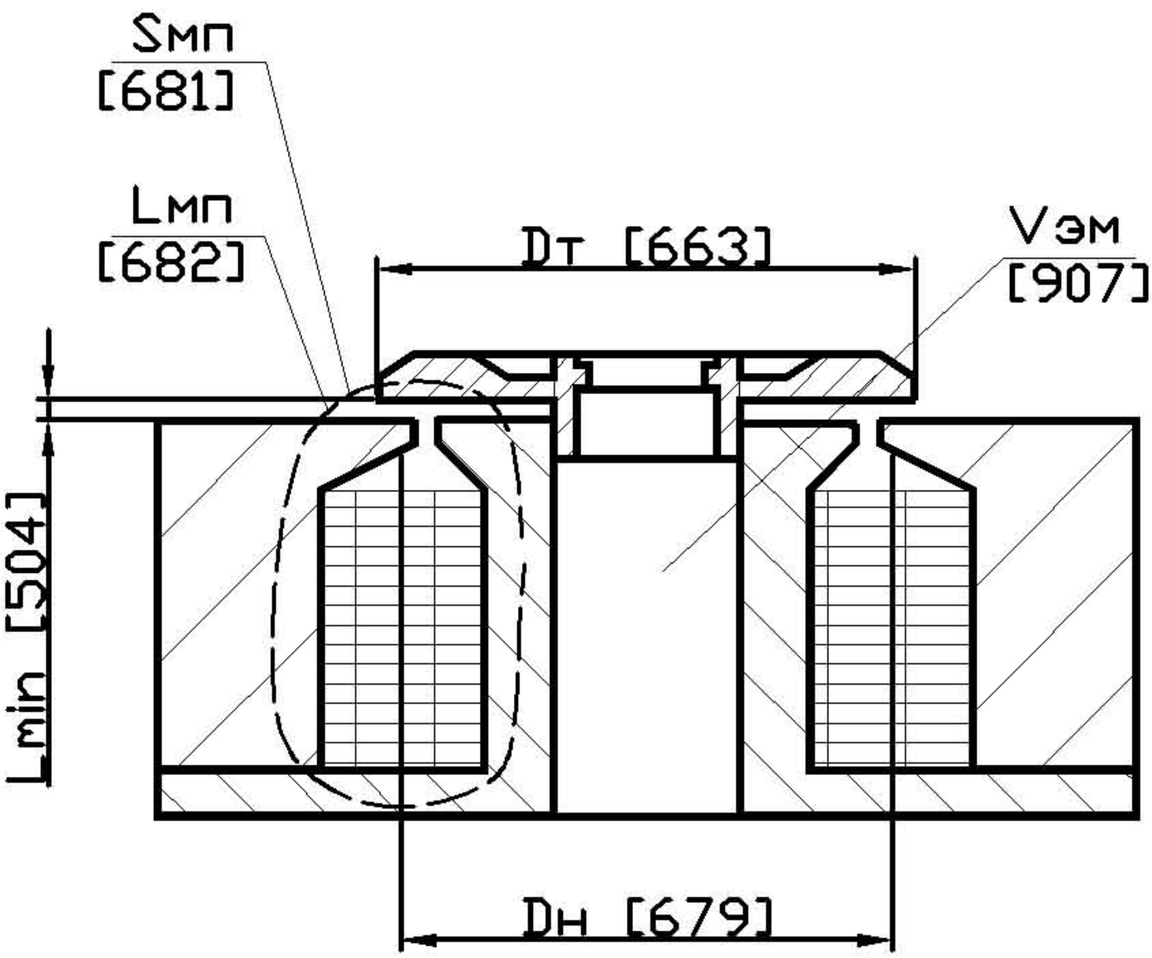


Fig.10 – Solenoidparameters

Solenoid parameters:

* **[679]** – Mean diameter of coil, mm
* **[681]** – Magnetic circuit cross-sectional area near the plunger gap, mm²
* **[682]** – Gap cross-sectional area for each magnet pole, mm^2

Hydraulic solenoid parameters:

- **[663]**–Solenoidvalveplatediameter, mm
- **[664]** – Minimum clearance between coil and plunger, mm
- **[907]** – Unloading plunger closed chamber volume (often it is solenoid chamber) at the seated valve (set >10^6 in case of no plunger), mm³
- **[909]** – Effective cross-sectional area of balancing channel between unloading plunger chamber (solenoid chamber) and valve chamber (pay attention to necessity for fine calculation step, especially if cross-sectional area >0.5...1 mm^2), mm²

[Fuel and materials properties] menu

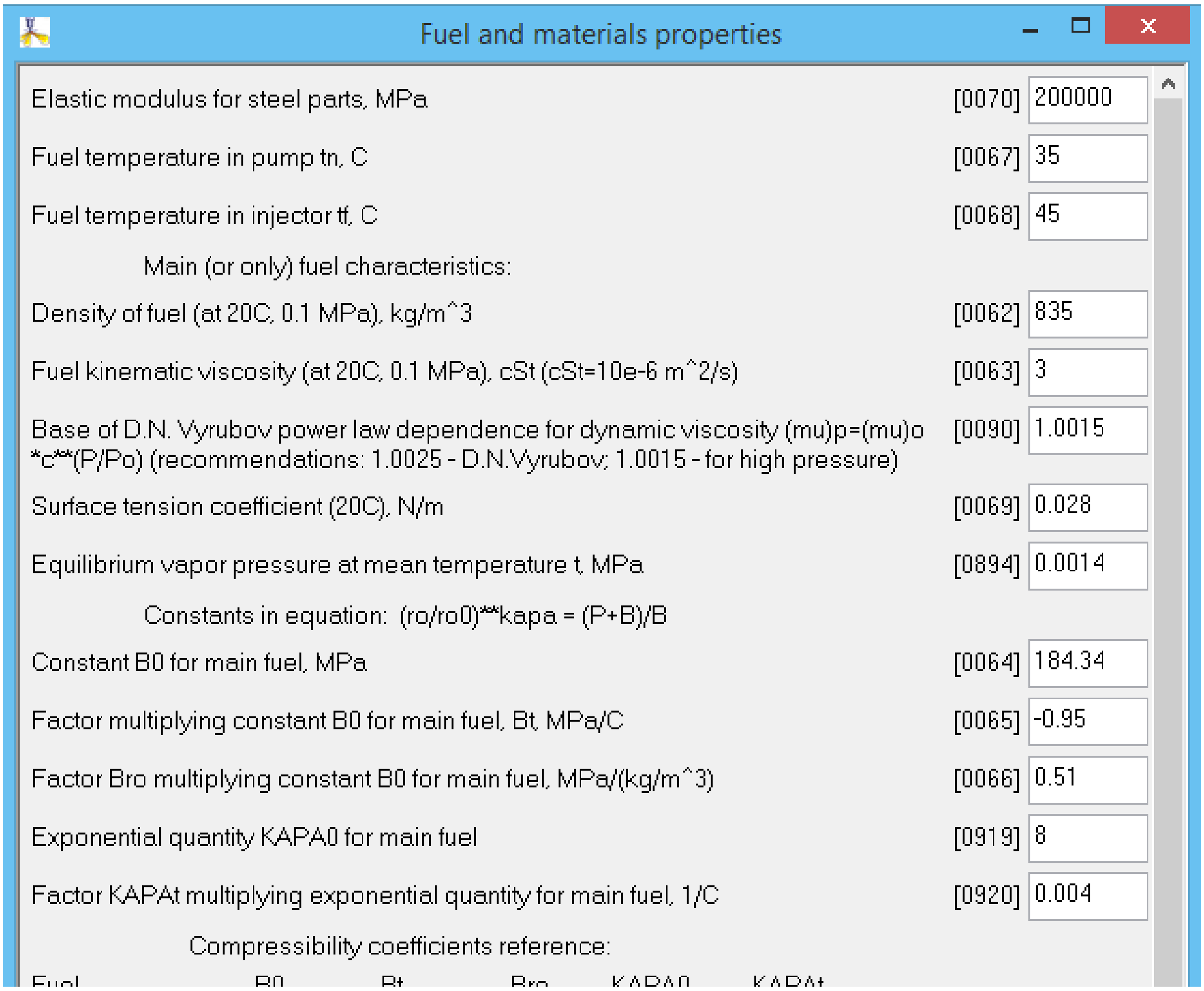


Fig.11 – [Fuel and materials properties] window

Inthismenu (fig. 11) general materials and fuel properties and some formulas factors are specified.

Ifitisusedonlyonefuelthenit’spropertieslike**density** [062] (at 20°Cand 0.1 MPa), **kinematic viscosity**[063](at the same conditions), **surface tension coefficient** [069] and**equilibrium vapor pressure** at mean temperature [894] are specified. If you use an additional fuel you should specify its properties the same way. Also in this window you can find some physical properties and compressibility coefficients of general fuel types.

Parameters for the compressibility formula $\frac{\rho}{\rho_0}^{\kappa} = \frac{P+B}{B}$, are specified in the corresponding fields.

In case of two fuels, two variants of injection are available:

- Main and alternate fuel homogeneous mixture delivery.
- Main fuel delivered by HP pump; alternate – by ports.

[External files] menu

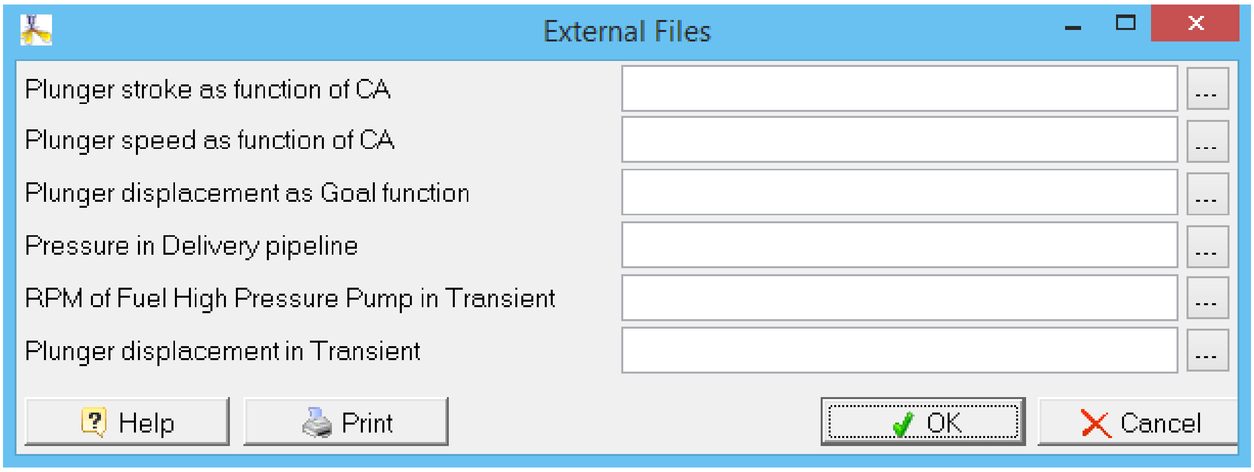


Fig.12 – [Externalfiles] window

Inthismenu (fig.12),youcansetpathstoexternaldatafilesareusedintheproject.

External files are stored and prepared independent of the main data file and the program. Its advantage is absence of necessity to enter values for each variant. The following external files types are allowed:

- Plunger stroke as function of CA – *.hpl
- Plunger speed as function of CA – *.cpl
- Plunger displacement as Goal function – *.pod
- Pressure in delivery pipeline – *.ptr
- RPM of HP pump in Transient mode – *.kul
- Plunger displacement in Transient mode – *.peq

All files have to be prepared using the following rules:

“Header” hasitsownform: any rows number with any text but all values have to be followed by keyword “Arrays”. Ifyouwanttowatchsuchdataingraphicforminprogram (likecalculationresults)you should use more complicated header that is listed below (row by row):

Legend (required keyword)

Some text (any rows)

Names (requiredkeyword)

AngleStroke (two variable names, only letters and numbers, divided by spaces)

Arrays (required keyword)

Next rows should contain variable values. Itcanberealorintegertypes(5. or 0.5E+01 or 5). Number of rows cannot exceed 150.

Dimensions: angles - deg, plunger stroke - mm, speed - m/s.

[Output data] menu

 - hotkey picture.

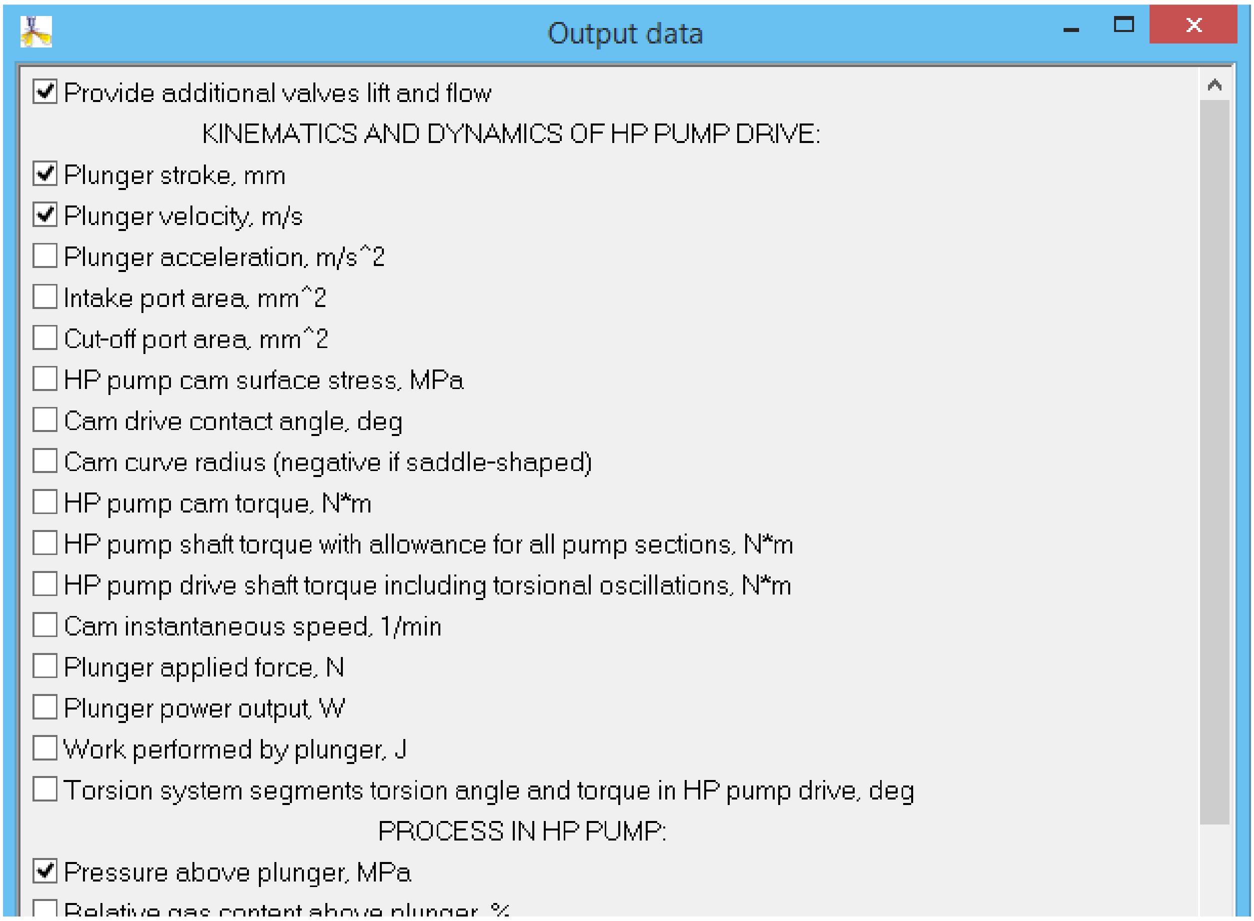


Fig.13 – [Output data] window

Inthiswindow (fig. 13),you can choose parameters that will be printed in calculation results.

It is possible to set scale dimension to ms in addition to angular. Also you can activate calculation of additional valves lift and flow.

Other parameters are combined to several groups:

- Kinematics and dynamics of HP pump drive.
- Processinhppump.
- Feeding tube and other tubes.

- Injectorgallery (othergalleries).
- Injector.
- Solenoid controlled dumping valve in HP pump.
- 1st control element solenoid drive.
- 2nd control element solenoid drive
- 1st controlvalvesolenoid.
- 2ndcontrolvalvesolenoid
- Needle or control plunger hydraulic control.
- Hydroimpulsiveneedlelocking.
- Unit injector controlled by plunger barrel ports.
- Plungerflexdriveparameters.
- Additionaloutputdata.

Please pay attention to the following two options of the last group:

- Instantaneous values in 1D scan results. Separateresultdatafiles identical to one-mode calculations for each pointwill be created during 1D scanning.
- Create new injection characteristic file to perform working process calculation. Thisfeaturecreatesadatafilewithinjectioncharacteristicinformatthatmaybeimp ortedtootherprogramstoperformcoupled calculation of fuel injection and in-cylinder processes (fig. 14).

Fig.14 – Coupled calculation scheme

[Elements] of Fuel System menu

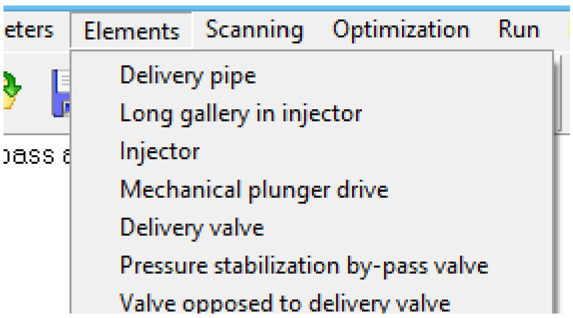
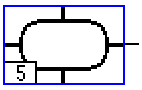


Fig.15 – [Elements] menu

Thismenu (fig.15) providesanaccessto properties of all elements used in selected scheme.

Also you can access fuel system elements parameters by double click at elements pics at the main screen.

[HP accumulator or drain] menu



- hotkey picture.

In this window (fig. 16)you can set parameters of HP accumulator of Common Rail system.

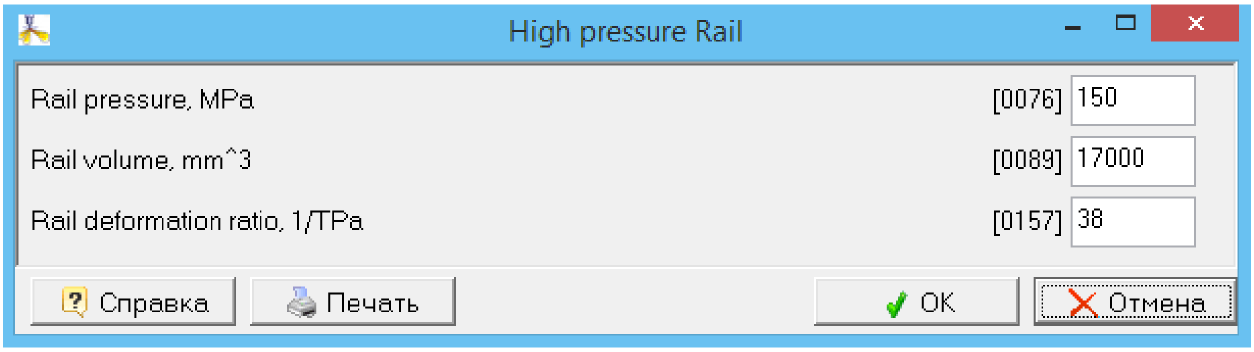
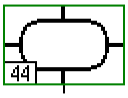


Fig.16 – [HP accumulator or drain] window

The following parameters are allowed:

- Railpressure, MPa – [076]. InCRsystemsthisvalueshouldbeequaltoinitialpressureinHPline (parameter [133] in [Operationalconditions…] menu). Inotherwayprogram will correct data automatically and show you a warning.
- Rail volume, mm^3 – [089].

[Injector make-up supply accumulator] menu

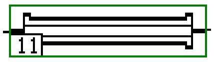


- hotkey picture.

In this menu you can set parameters of injector make-up supply accumulator.

It is available to set pressure in accumulator [088].

[Hydraulic lock pipe] menu



- hotkey picture.

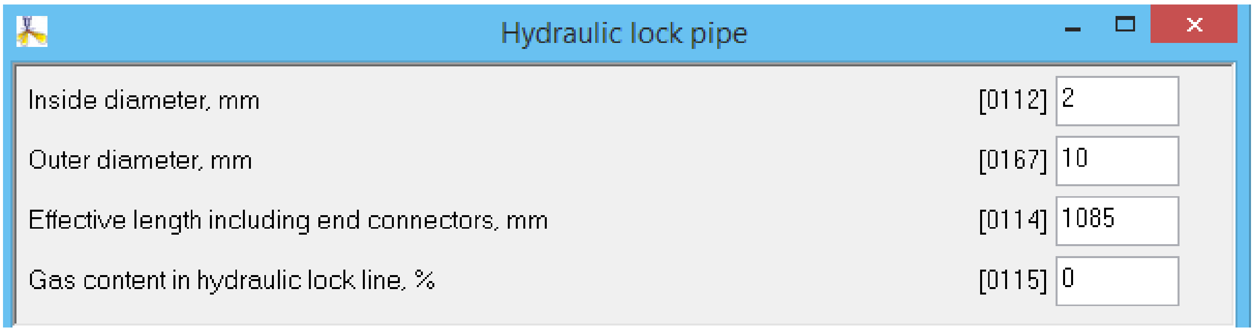
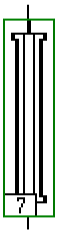


Fig17 – [Hydraulic lock pipe] window

Available parameters (fig. 17):

- Insidediameter, mm – [112]
- Outerdiameter, mm – [167]
- Effective length including end connectors, mm – [114]
- Gas content in hydraulic lock line, % - [115]

[Gallery between injector inlet and chamber below needle] menu


- hotkeypicture.

Inthismenu, (fig. 18) parameters of this gallery are specified. Short galleries may cause stability problem. Do not divide HP line if it is not necessary and do not use big calculation stepsize.

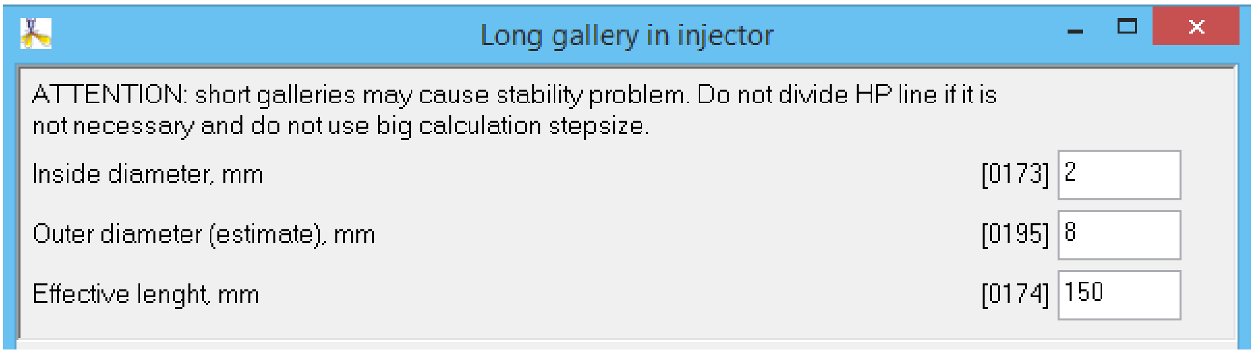


Fig. 18 – [Gallery between injector inlet and chamber below needle] window

The following parameters are available:

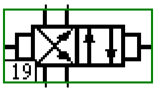
- Insidediameter, mm – [173]
- Outerdiameter (estimate), mm – [195]
- Effectivelenght, mm– [174]

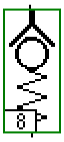
It is possible to use two different models:

- HPlineasonelongacousticline (this gallery is not separated from feed pipe);
- HPlineastwoseparatedlongacousticlines.

Calculation is more accurate if two volumes are used but calculation time and instability are increased too. Ifonlyonevolumeisused, then these volumes are summed and gallery diameter equals to pipe diameter, and excess volume (gallery diameter is greater than pipe diameter) is added to overall volume.

Valves



, 

-hotkey pictures.

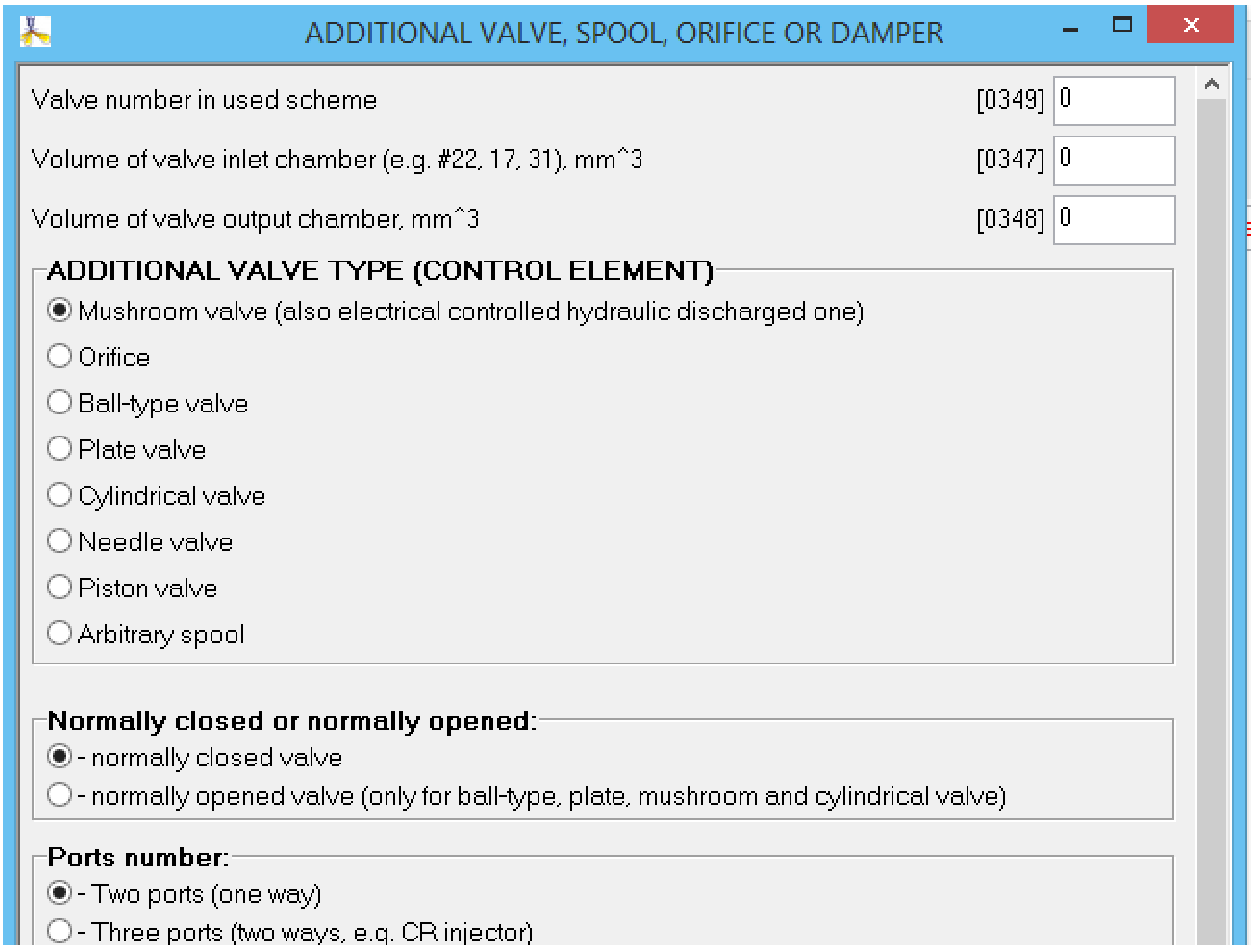


Fig.19 – Valveswindow

Each valve used in the scheme has individual parameters (fig. 19). Numberofvalvethatcorrespondingtothecurrentparametersset should be specified in the [349], [399], [449] field.Athotkeypicturesexamplesitis19and8.

Scheme of generic valve is show atfig. 20.

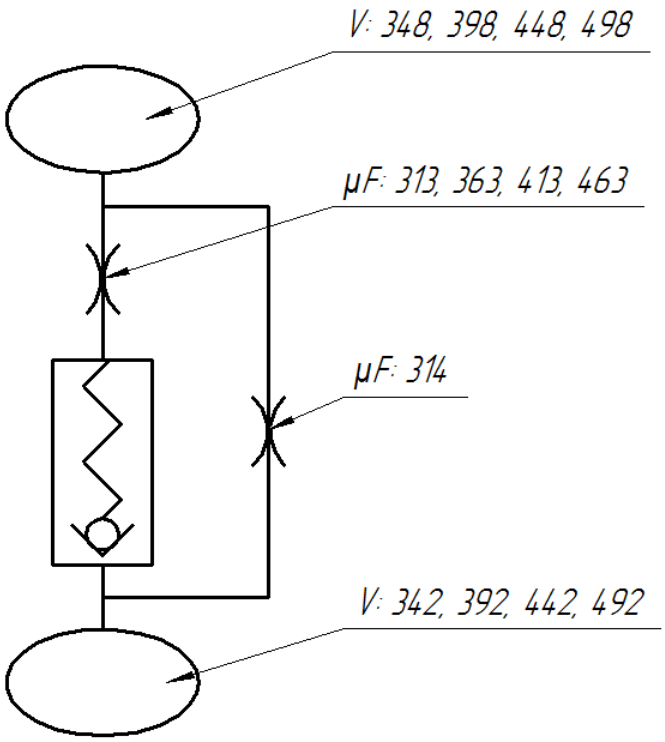


Fig.20 – Scheme of valve

- [348], [398], [448], [498] – Volume of valve output chamber, mm^3.
- [313], [363], [413], [463] – Effective cross-sectional area of orifice connected to spool in series, mm^2.
- [342], [392], [442], [492] – End volume of hydraulic control chamber, mm^3.

Afterchoosingthevalvetype,youcansetitsnormalstate:normally closed or normally opened (only for ball-type, plate, mushroom and cylindrical valve).

Also it is possible to specify valves by number of ports: two ports (one way) or three ports (two ways). Such valves may be used to switch hydraulic control chamber from HP accumulator to drain or to switch HP accumulator from control chamber to injector (#16, 19).Usuallythesevalvesarenormallyclosed. Valve opening pressure [010] may be negative.

Valve movement analysis cab use hydro mechanical force balance (for self-acting valves) or solenoid force.

Valve may be defined both as pressure-compensated and as not compensated. Pressurecompensatedvalvesreducessolenoidforce.

Below you can see some geometric parameters of different valve types.

- **Mushroom type, not compensated, two ports, normally closed valve**

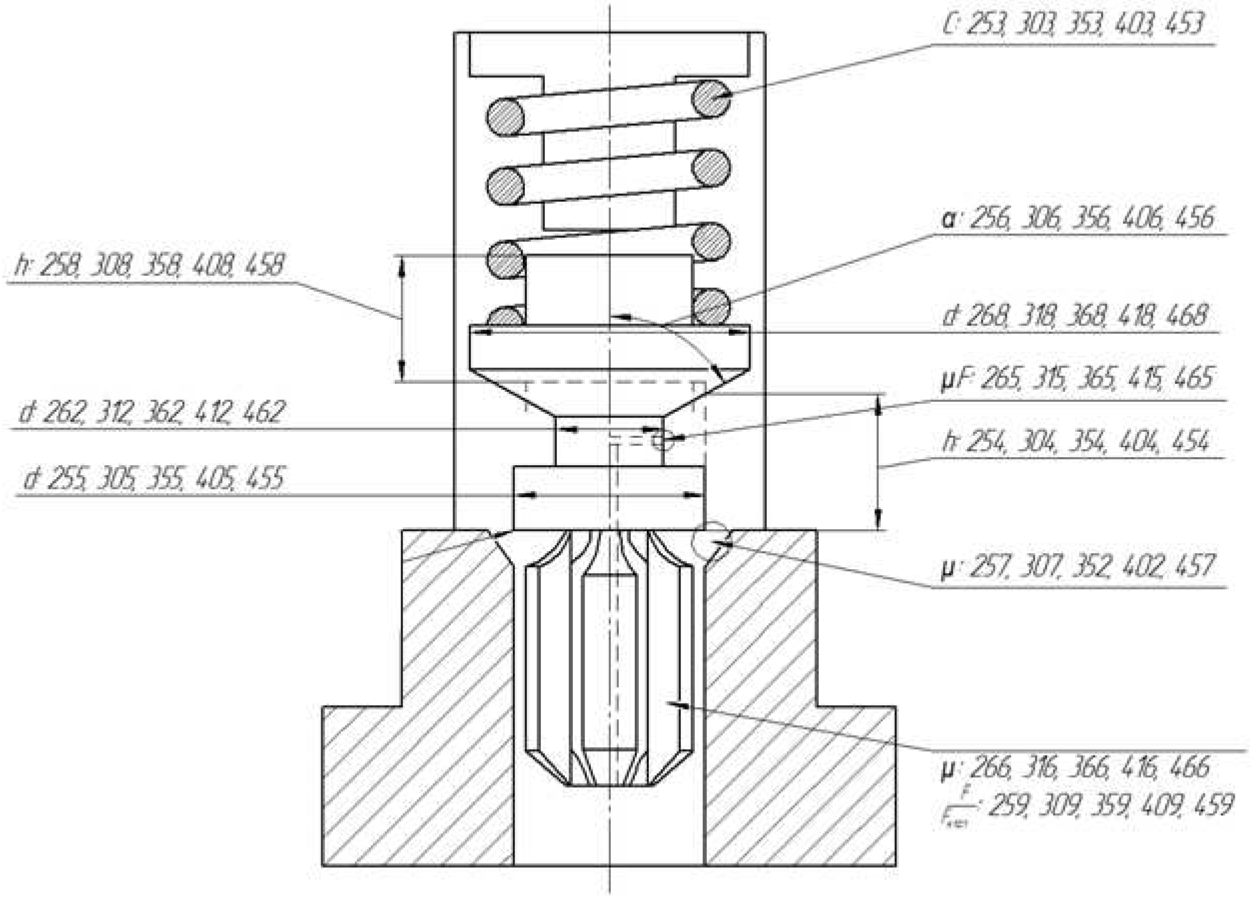


Fig.21 – Mushroom type, two ports, normally closed valve

- [253], [303], [353], [403], [453] – Valve spring stiffness, N/mm.
- [254], [304], [354], [404], [454] – Valvedischargestroke, mm.
- [256], [306], [356], [406], [456] – Half angle of valve seat cone, deg.
- [257], [307], [357], [407], [457] – Effective cross-sectional area of orifice connected to 2nd spool port, mm^2.
- [258], [308], [358], [408], [458] – Maximumvalvestroke, mm.
- [259], [309], [359], [409], [459] – Area ratio of valve guides. $F_{напр}/F_{клап}$

- [255], [305], [355], [405], [455] – Valve diameter (for ball-type, plate, pressure-compensated mushroom - external diameter, in other cases - minimal seat cone diameter, usually equals to cylindrical precision surface diameter), mm.
- [265], [315], [365], [415], [465] – Effective cross-section area of corrector valve galleries, mm^2.
- [266], [316], [366], [416], [466] – Flow coefficient of valve guides.
- [268], [318], [368], [418], [468] – Maximum diameter of valve body seating cone, mm.

- **Mushroomtype pressure compensated valve**

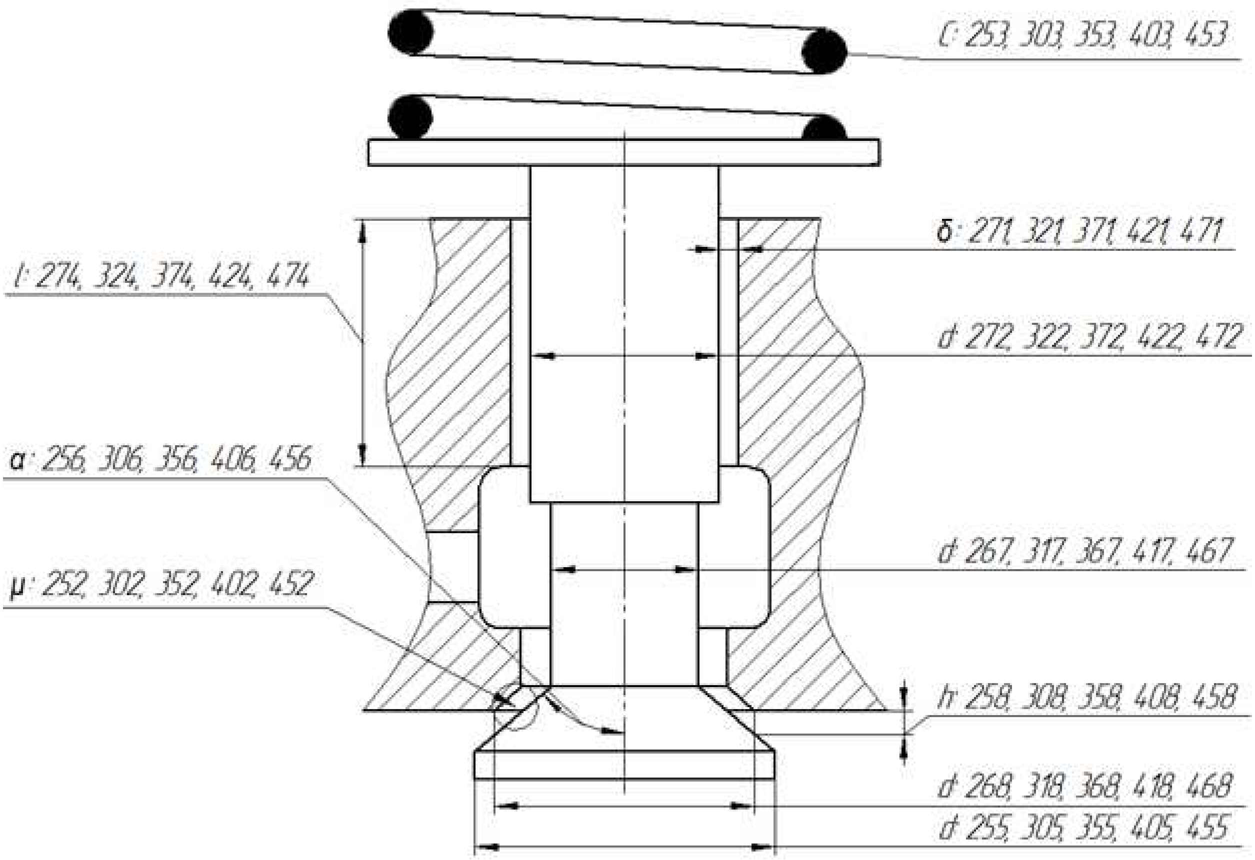


Fig.22 – Mushroom type pressure compensated valve

- [267], [317], [367], [417], [467] – Diameter of stem between face and balanced plunger, mm.

- [271], [321], [371], [421], [471] – Radial clearance in precision pair, um.
- [272], [322], [372], [422], [472] – Discharging plunger diameter (this plunger discharges electrical controlled valve from high pressure at inlet and has balancing channel between drain chamber and plunger back side), mm.
- [274], [324], [374], [424], [474] – Plunger sealing length (0 if absent), mm.

- **Ball type valve**

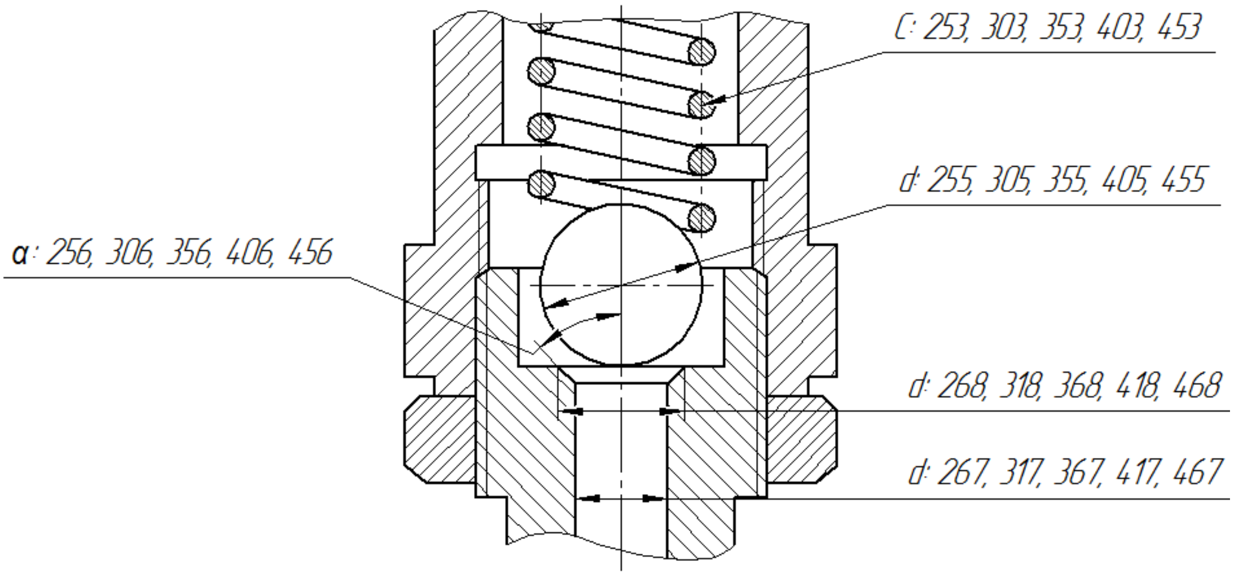


Fig.23 – Balltypevalve

- [255], [305], [355], [405], [455] – Ball diameter, mm.
- [256], [306], [356], [406], [456] – Half angle of valve seat cone, deg.
- [267], [317], [367], [417], [467] – Minimal seat cone diameter, mm.
- [268], [318], [368], [418], [468] – Maximum seat cone diameter, mm.

- **Cylindrical valve**

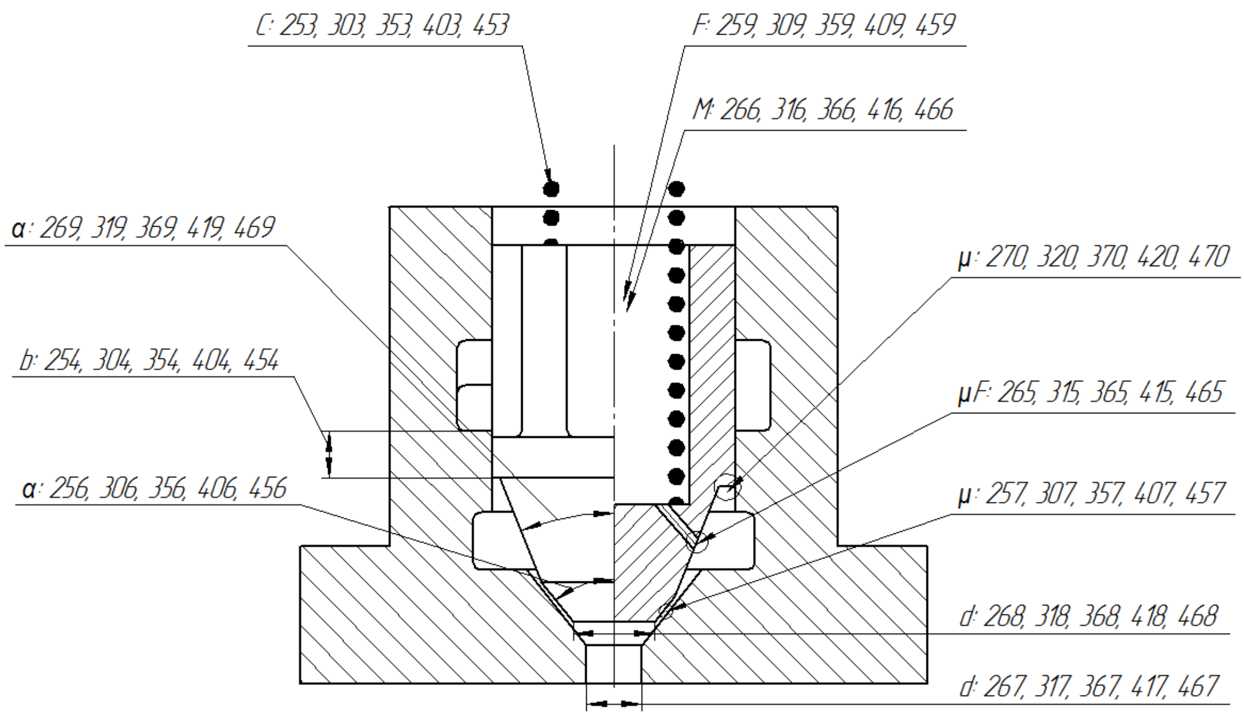


Fig. 24 – Cylindricalvalve

- [270], [320], [370], [420], [470] – Valve flow coefficient at relieving shoulder.
- [269], [319], [369], [419], [469] – Half angle of seating cone, deg.
- [267], [317], [367], [417], [467] – Minimal diameter of seat cone, mm.

- **Plate valve**

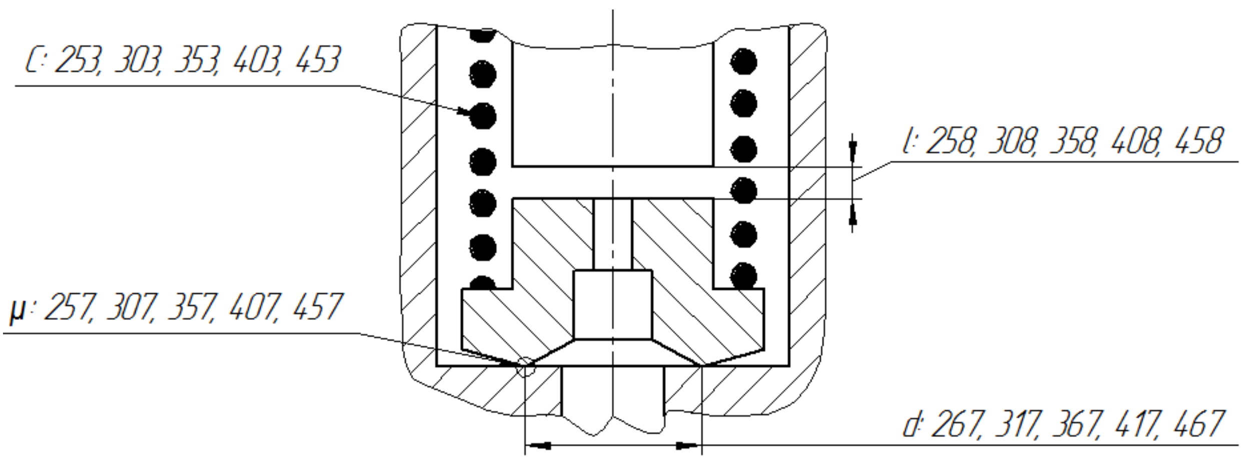


Fig.25 – Platevalve

- o [267], [317], [367], [417], [467] – Minimal diameter of closing surface, mm.

- **Piston valve**

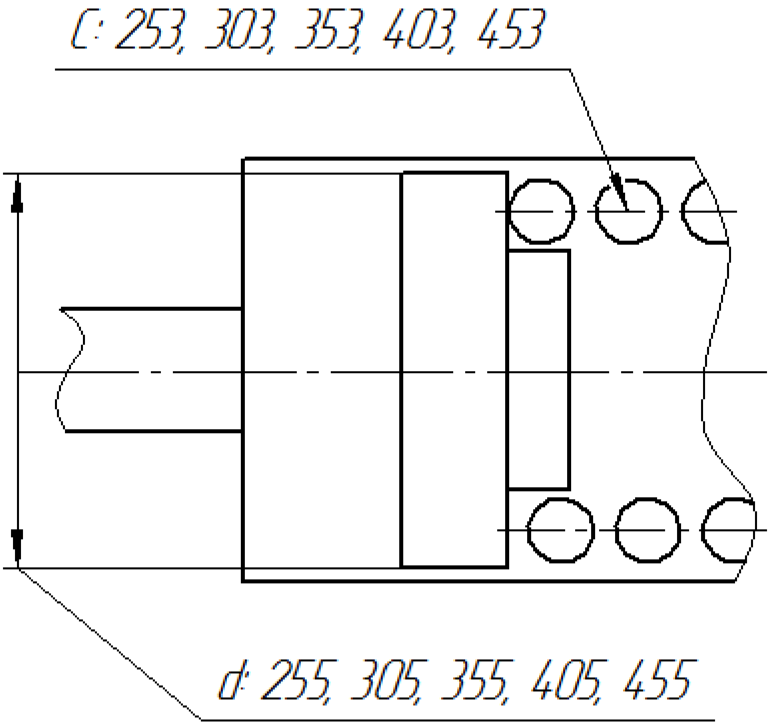


Fig.26 – Pistonvalve

- **Spool**

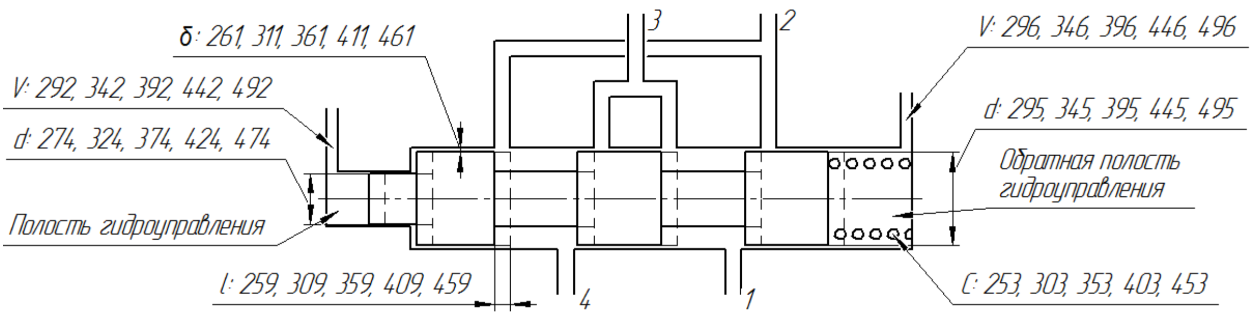


Fig.27 – Spool

Dashedlineatfig. 27it the position of spool after beginning of control signal and spool movement.

Below are some spool parameters available in the current menu:

- [253], [303], [353], [403], [453] – Stiffness of spool spring, N/mm.
- [274], [324], [374], [424], [474] – Diameter of end face under influence of control pressure (if =0 then spool is uncontrolled), mm.
- [292], [342], [392], [442], [492] – End volume of hydraulic control chamber, mm^3.
- [295], [345], [395], [445], [495] – Diameter of opposite sided end face under influence of pressure returning spool to initial position (if =0 then spool returns by spring), mm.
- [296], [346], [396], [446], [496] – Dead volume in opposite sided hydraulic control chamber, mm^3.
- [261], [311], [361], [411], [461] – Radial clearance between spool and housing, um.
- [263], [313], [363], [413], [463] – Controlprofilesflowcoefficient.
- [265], [315], [365], [415], [465] – Diameter of circular profiles or height of rectangular ones, mm.
- [266], [316], [366], [416], [466] – Length of control slot or annular groove, mm.
- [273], [323], [373], [423], [473] –Number of spool control profiles (cylindrical spool helical groove is equal to 1 control profile).

Control ports cross-sectional area also may be defined by table function *CrossSectionArea=f(Stroke)* (fig. 28).In this case, maximum stroke is equals to the maximum of table function.How to use table functions you can see in the corresponding chapter: *Charts editing*.

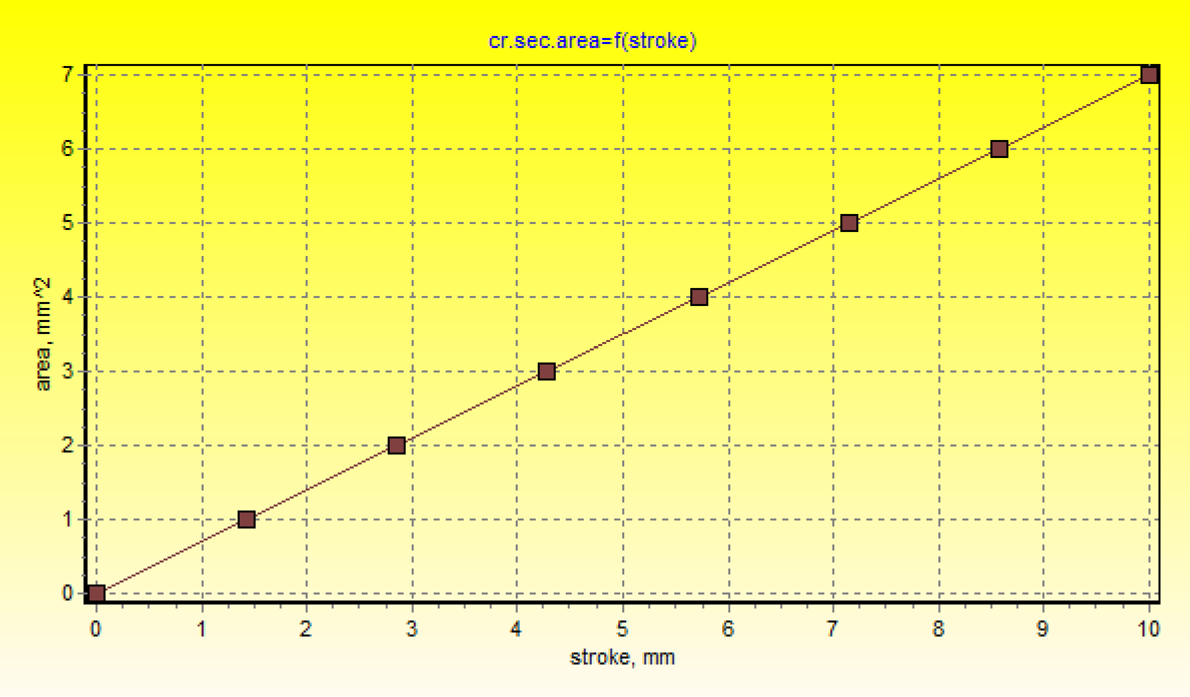
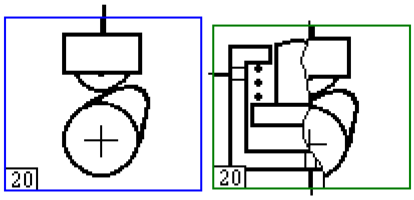


Fig.28 – Table function

[Mechanical plunger drive] menu



- hotkey pictures.

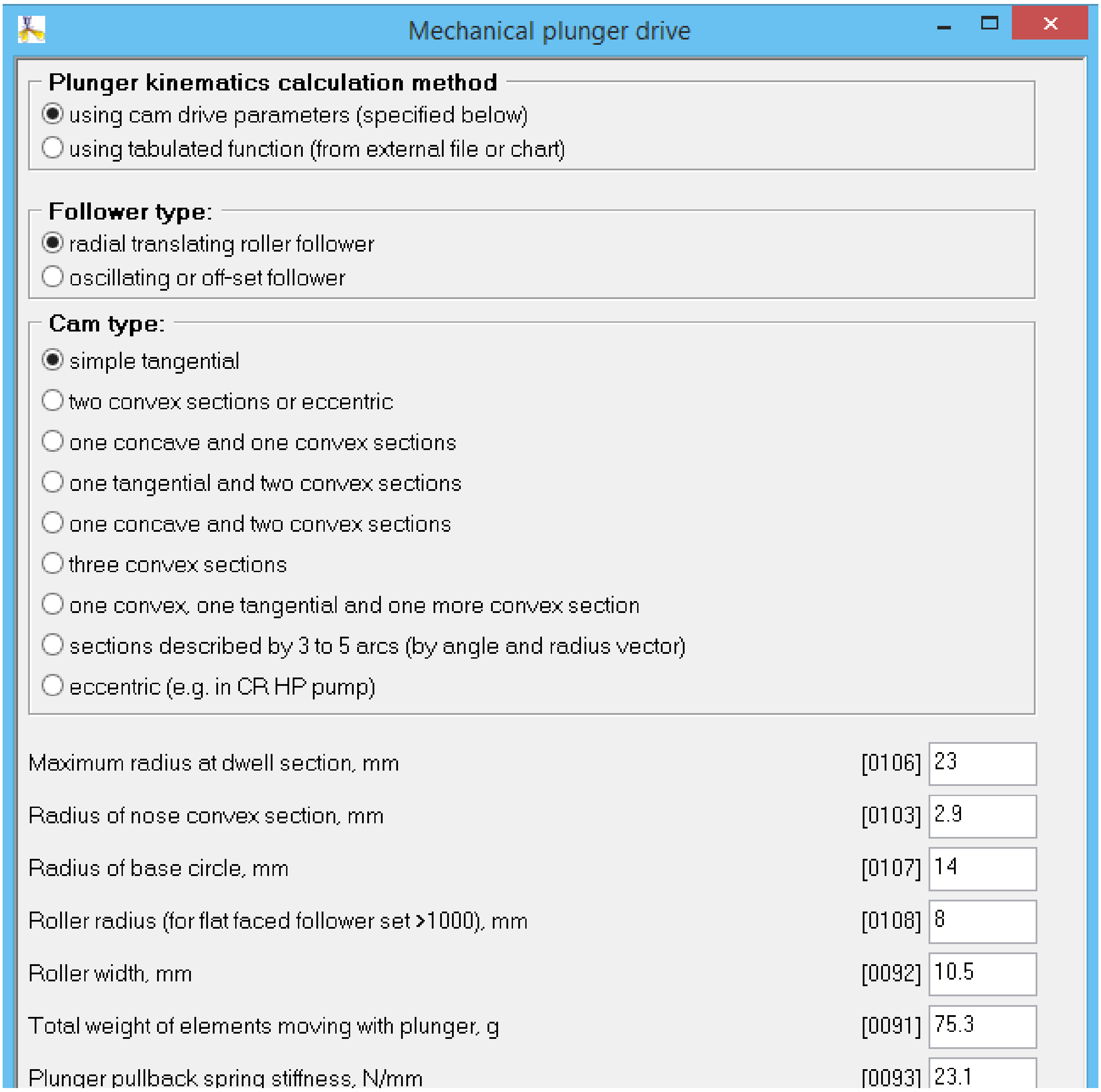


Fig.29 – [Mechanical plunger drive] window

Calculation is possible using both radial translating roller follower and oscillating (or offset) follower, fig. 30. Inthesecondcase, plungerstrokeh_{pl}isnotequaltothe followers lift h_f and the following parameters should be specified:

- Rocker arm roller end length (distance between roller axis and rotation axis of rocker arm), mm – [095]
- Primecircleradius, mm – [096]
- Rocker arm tappet end initial angle (0 if tappet end axis is perpendicular to tappet axis), deg – [097]
- Rocker arm lever ratio (ratio of plunger stroke to roller displacement) – [098]
- Cam rotation direction:cam nose moves toward or outward roller.

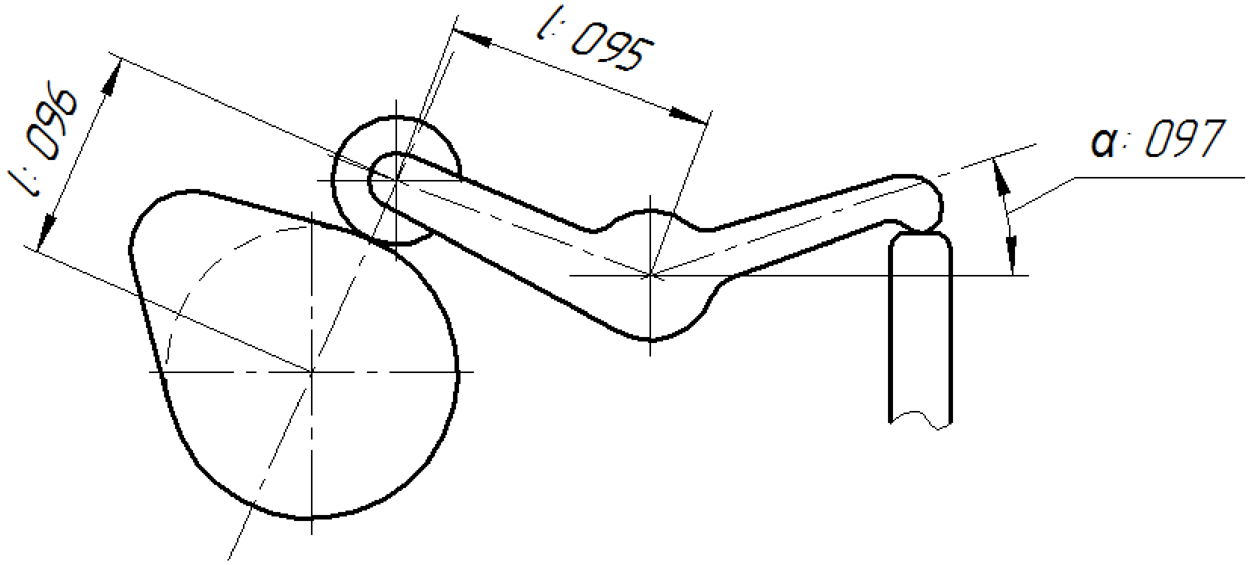


Fig.30 – Oscillatingfollowerscheme

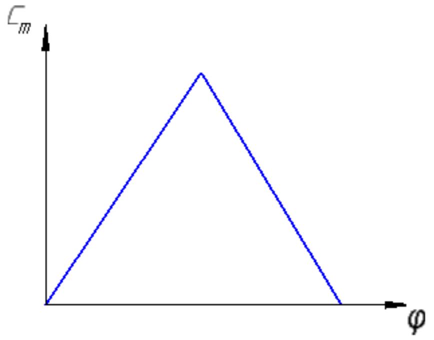
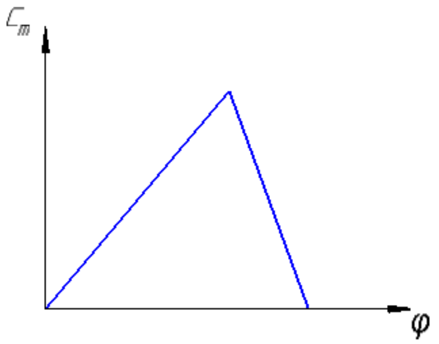
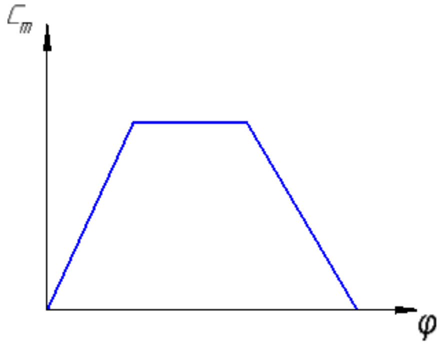
Themostcommonusedcamtypesandvelocity profiles are shown in the table 1. Some remarks:

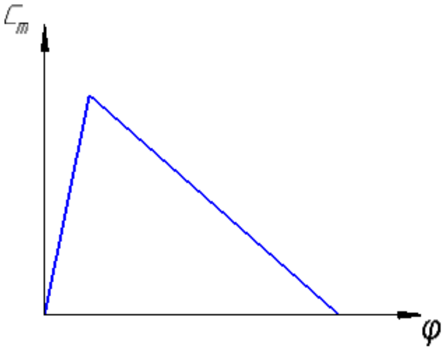
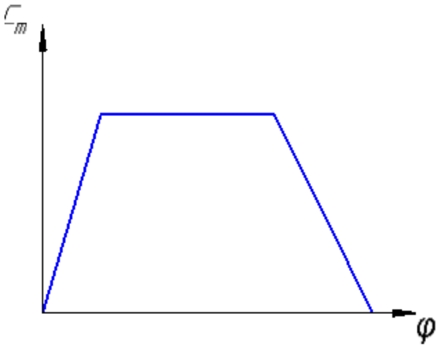
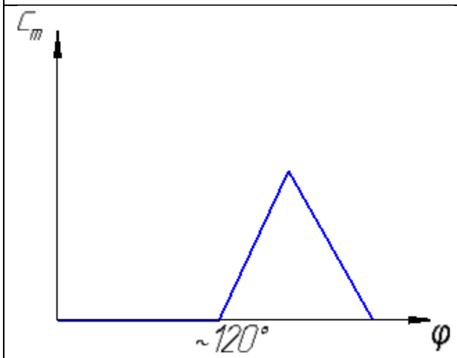
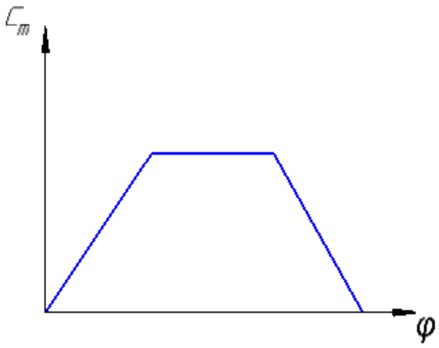
- Tangentialsectionisthecheapest.
- Threeworkingprofilesmakepossibletouseadwell section instead of triangle.
- Concave section causes higher velocity.

Inaddition, the cam with one concave and two convex sections is one of the most useful ones due to higher follower velocity c_f and the dwell with constant velocity.Thesamereasonsmakecam with one tangential and two convex sectionsthe second most useful cam.

In systems with cam with convex, tangential and one more convex sections the lift begins only from the tangential section.

Table1 – Cam types

Velocity profile	Description
	One tangential and one convex sections
	Two convex sections
	Three convex sections

Velocity profile	Description
	One concave and one convex sections
	One concave and two convex sections
	One convex, tangential and one more convex sections
	One tangential and two convex sections

Cam parameters are shown at fig. 31.

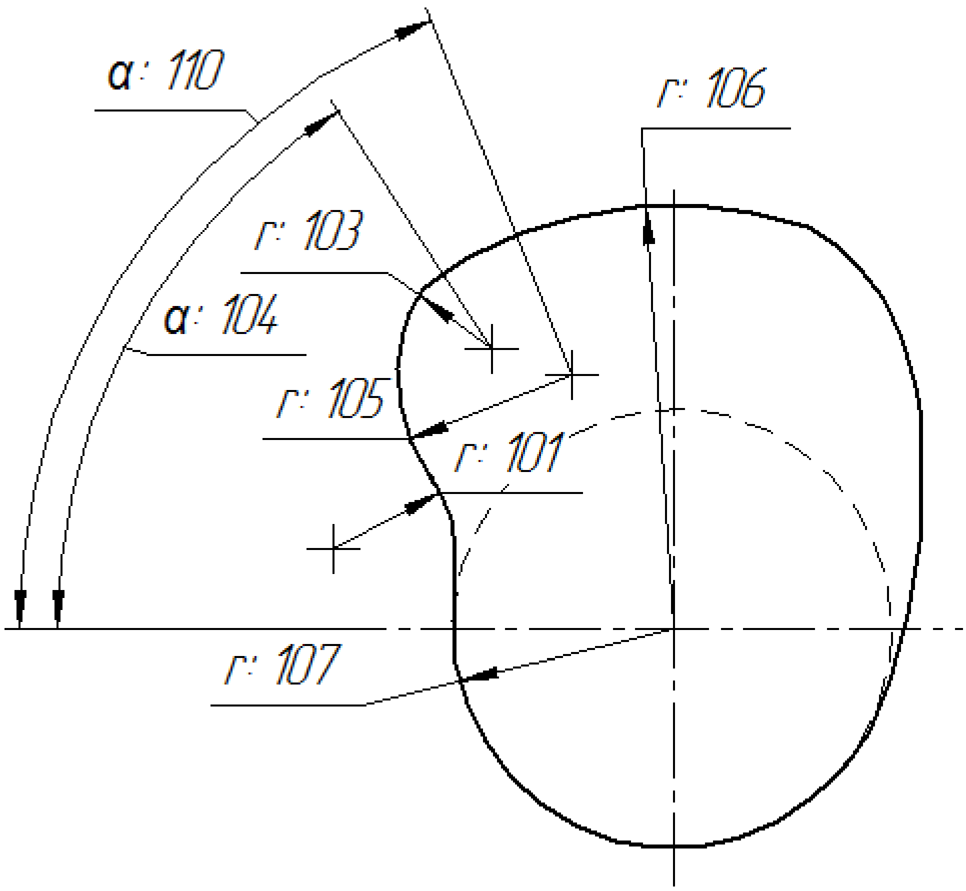


Fig.31 – Camparameters

- [101] – Radius of 1st convex/concave section, mm
- [103] – Radius of nose convex section, mm
- [104] – Angle of nose convex section center, deg
- [105] – Radius of intermediate convex section, mm
- [106] – Maximum radius at dwell section, mm
- [107] – Radius of base circle, mm
- [110] – Assessment angle of intermediate section center, deg

Itispossibletoperformcalculationswitheccentricby specifying radius of base circle [107] and eccentricity (1/2 of full plunger stroke summed with the difference between eccentric radius and base radius) [112].

Alsoitisallowedtousecamprofiledescribedby 3 to 5 arcs (byangleandradiusvector).

Follower parameters are shown atfig. 32.

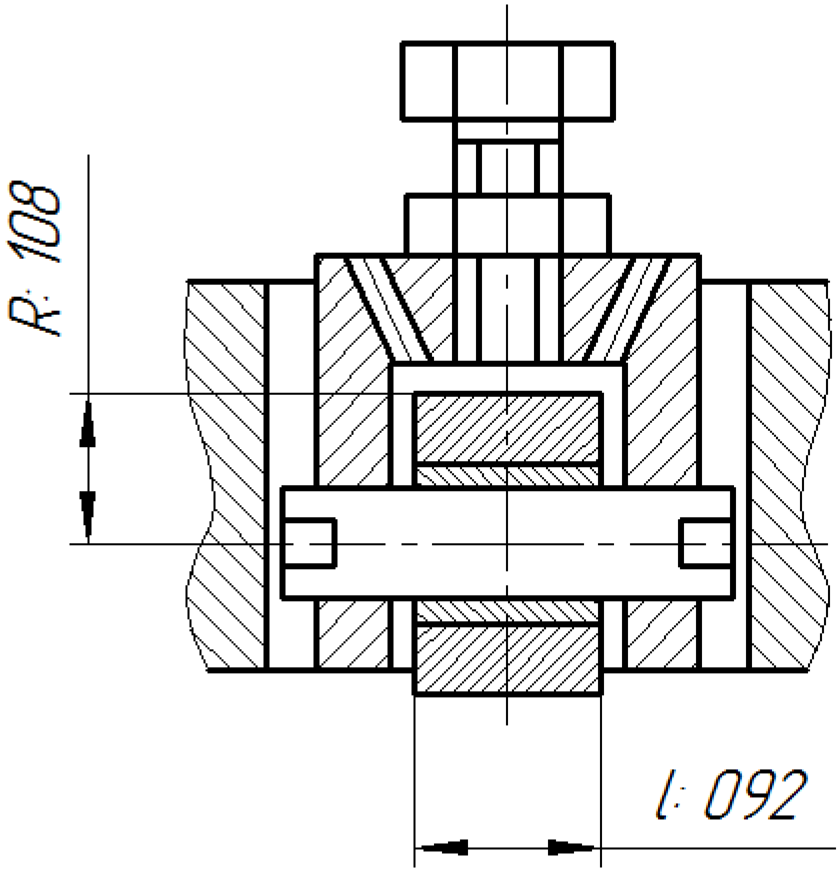
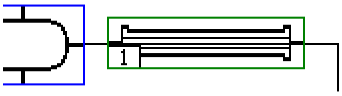


Fig.32 – Follower

- [092] – Roller width, mm. Widthofcontactlinebetweenrollerandcam.
- [108] – Rollerradius, mm.

[Delivery pipe] menu

Deliverypipeis long acoustic element with wave processes in it.



- hotkey picture.

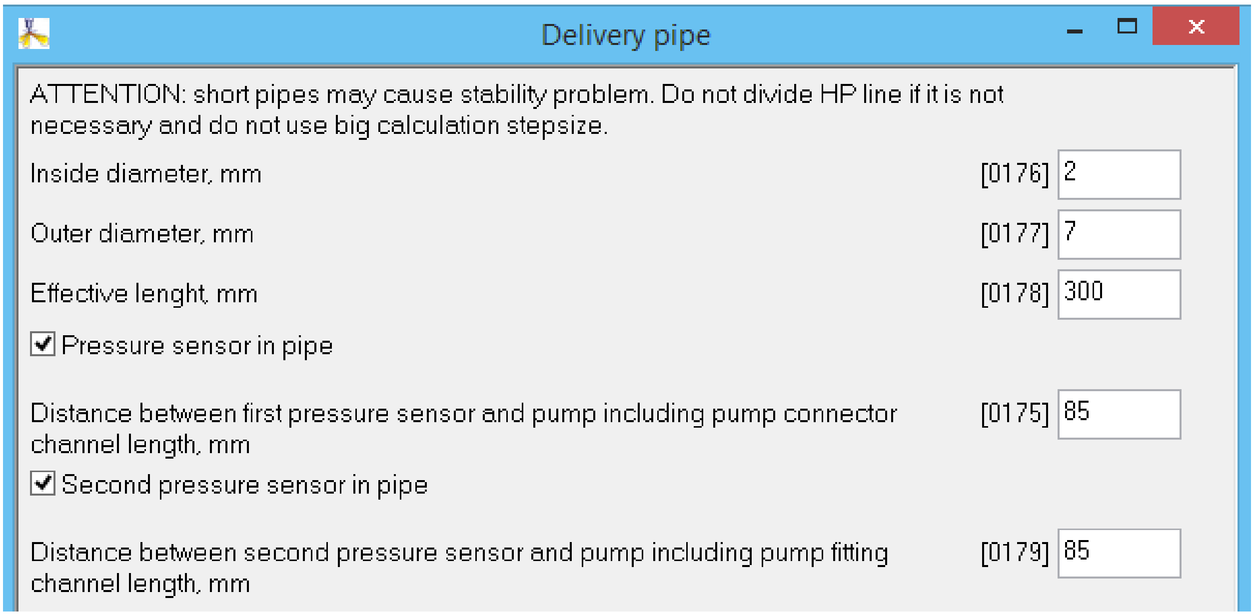


Fig.33 – [Deliverypipe] window

Inpump-line-injectorsystemsadeliverypipe (fig. 33)isplacedbetweenHPpumpandinjector, in CommonRail systems it is between HP accumulator and injector and also between HP pump and HP accumulator..

Recommendations:

- Lengthcalculationisperformedwithallowanceforchannelsinendconnectorsof HPpumpandinjector.
- Calculationofpipesshorterthan ~100 mm may be unstable. Inthiscase,itisnecessarynottocalculatepipebut to use an additional volume instead of pipe.
- Pleasepayattentionto the accuracy of inner diameter specifying.
- Avoid extreme values.

- Ifpressuresensorsareused,youhavetoincludeitsadditionallengthanditspositionsismeasuringfromthebeginningofthepipe.

Parameters:

- **Insidediameter, mm** – [176]
- **Outerdiameter, mm**– [177]
- **Effective lenght, mm**– [178]

Pump fitting channel length + pipe + pressure sensor + injector gallery.

Itispossibletotake pressure sensorsintoaccount (fig. 34). Distance between sensors and HP pump is setting in the following fields:

- **Distance between first pressure sensor and pump including pump connector channel length, mm** – [175]
- **Distance between second pressure sensor and pump including pump fitting channel length, mm**– [179]

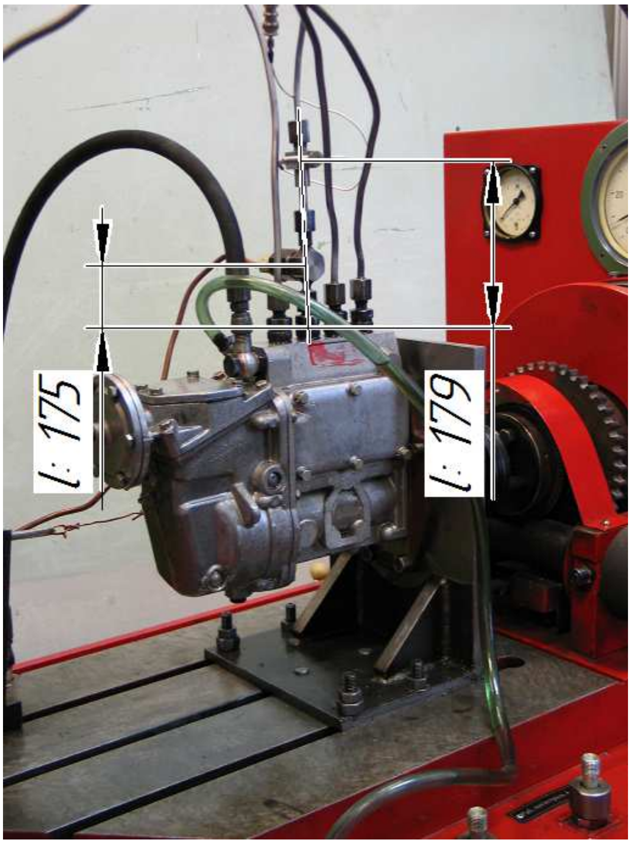
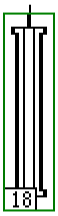
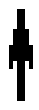


Fig.34 – Pressuresensorsinpipe

[Feed pipe] menu



 - hotkey picture.

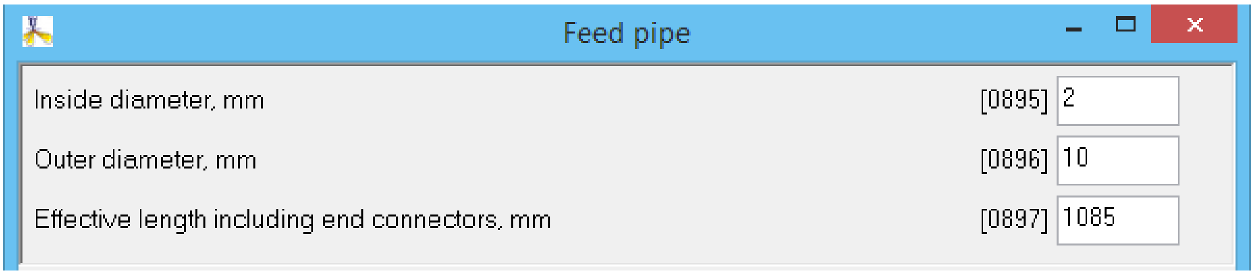
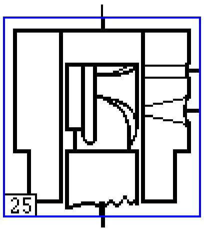


Fig.35 – [Feed pipe] window

The following parameters are used (fig. 35):

- Insidediameter, mm – [895].
- Outerdiameter, mm – [896].
- Effective length including end connectors, mm – [897].

[Plunger pair] menu



- hotkey picture.

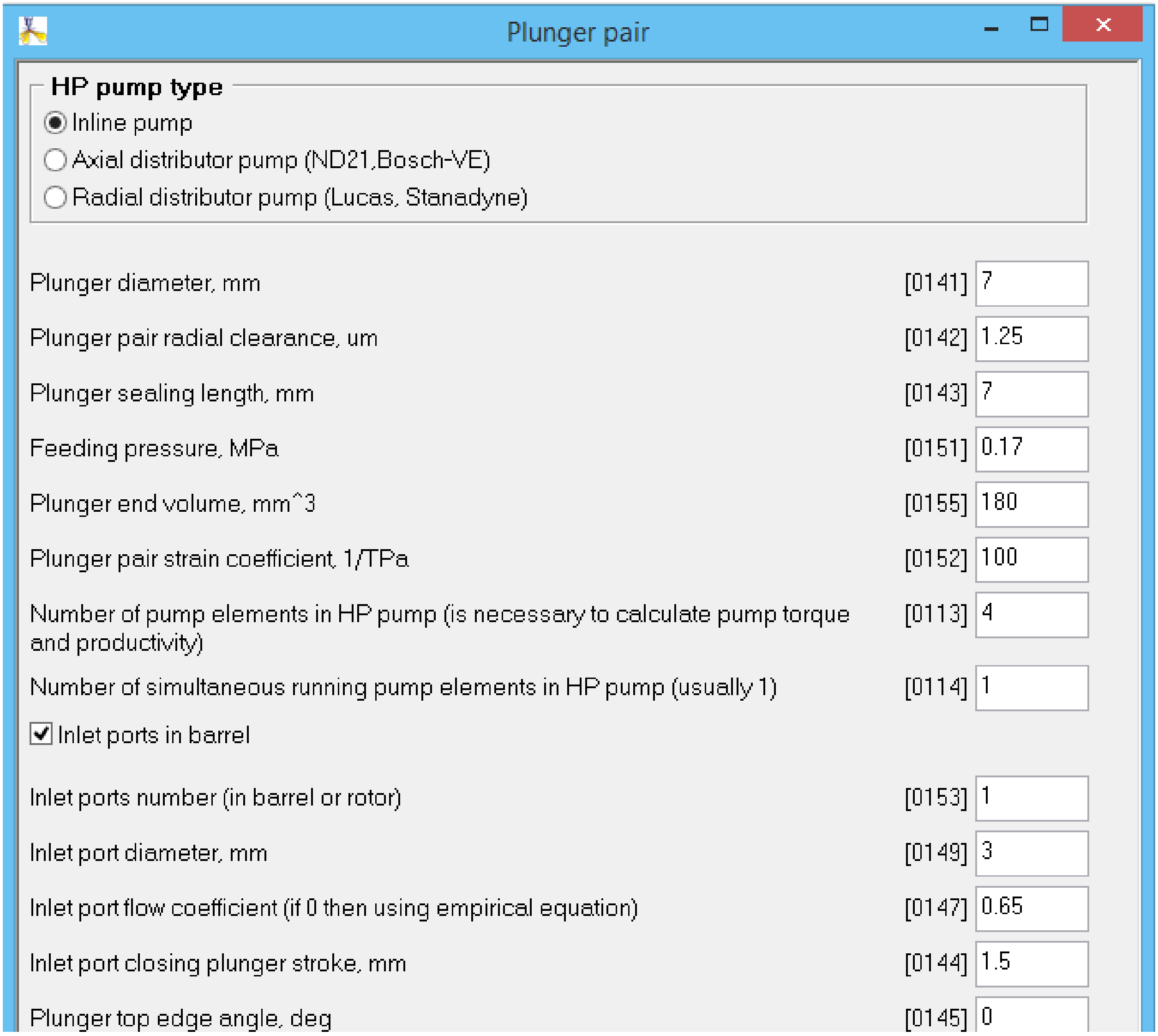


Fig. 36 – [Plunger pair] window

The following types of HP pumps are available:

- Inline pump.
- Axial distributor pump (ND21,Bosch-VE).

- Radial distributor pump (Lucas, Stanadyne).

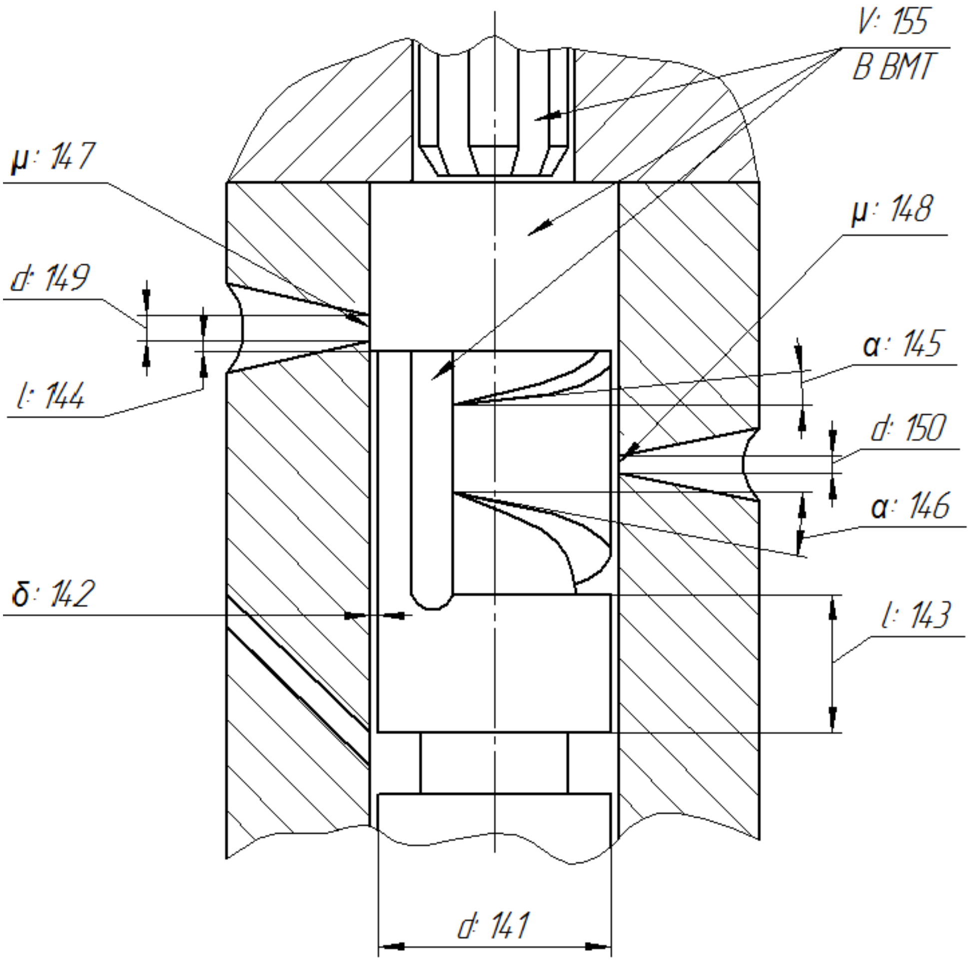


Fig.37 – Geometric parameters of plunger pair

Plunger pairs parameters (fig. 37):

- **Plungerdiameter, mm** – [141]
- **Plunger pair radial clearance, um** – [142]
- **Plungersealinglength, mm** – [143]
- **Feedingpressure, MPa** – [151]
- **Plungerendvolume, mm^3** – [155]
- **Plunger pair strain coefficient, 1/TPa** – [152]
- **Number of pump elements in HP pump (is necessary to calculate pump torque and productivity)** – [113]
- If inlet ports are presented:

- **Inlet ports number (in barrel or rotor)** – [153]
- **Inletportdiameter, mm**– [149]
- **Inlet port flow coefficient (if 0 then using empirical equation)**– [147]
- **Inlet port closing plunger stroke, mm** – [144]
- **Plunger top edge angle, deg** – [145]

- If cut-off ports are presented:
  - **Cutting-off ports number (in barrel or rotor)** – [154]
  - **Cutting-off port diameter, mm** – [150]
  - **Cutting-off port flow coefficient (if 0 then using empirical equation)** – [148]
  - **Plunger cutting-off edge angle, deg** – [146]

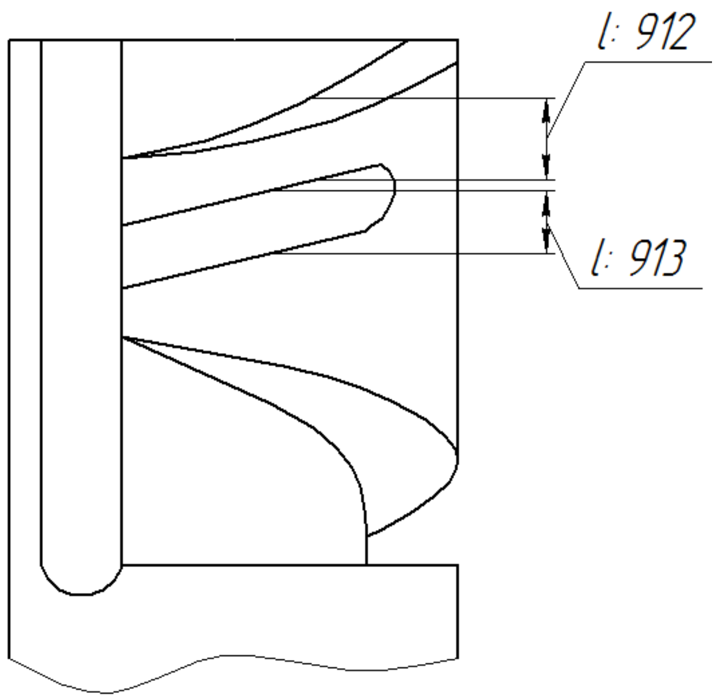


Fig.38 – Geometric parameters of groove in plunger

- If groove at the top of plunger for two-stage injection is presented:
  - **Plunger sealing width between top edge and first cutting-off groove, mm** – [912], seefig. 38.

- **First cutting-off groove width, mm** – [913], seefig. 38.

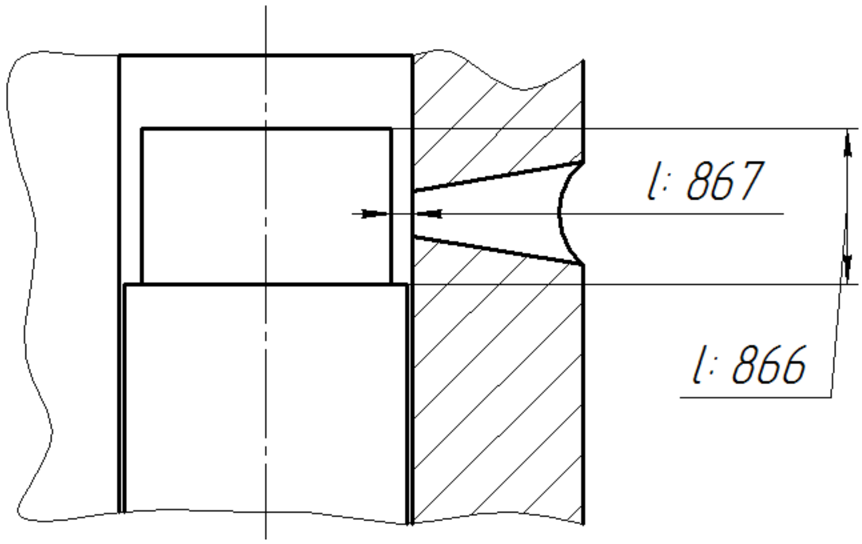


Fig.39 – Geometric parameters of groove in top of plunger

- Groove at the top of plunger for automatic advance angle regulation is presented:
  - **Groove height (from the top edge), mm** – [866], seefig. 39.
  - **Radial clearance in plunger-barrel pair at the groove level, um** – [867], see fig. 39.

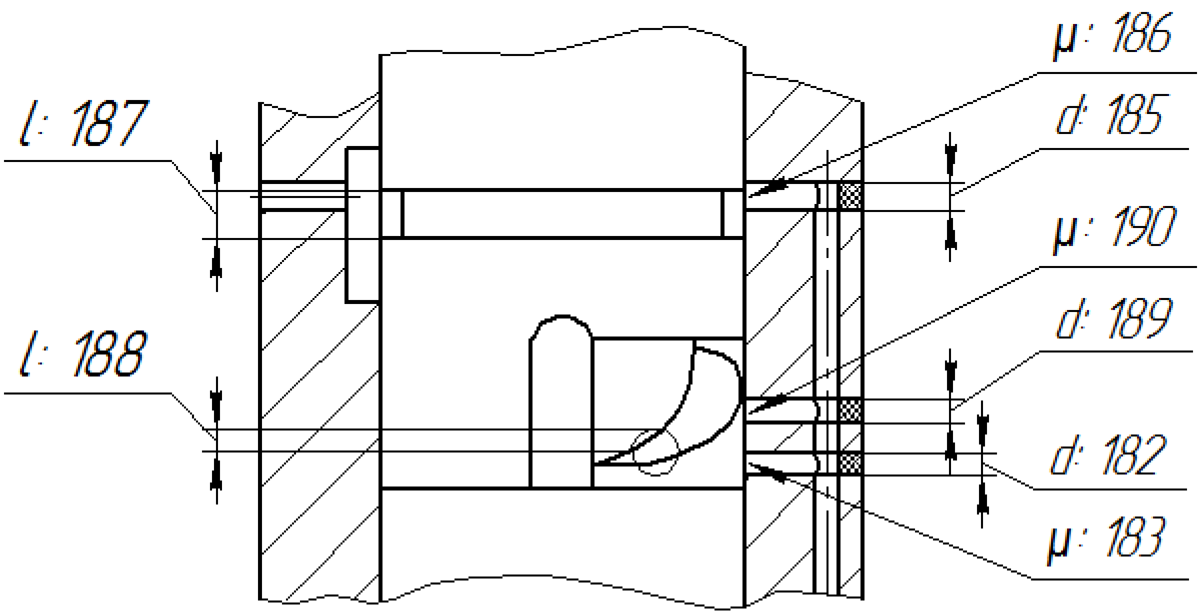
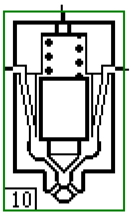


Fig.40 – Geometricparametersofbarrel

- Above needle chamber pre-charge port is presented (fig. 40):
    - **Plunger stroke when charge port closing begins, mm** – [181]
    - **Chargeportdiameter, mm** – [182]
    - **Chargeportflowcoefficient** – [183]
- Intermediate throw-off port (beginning of injection) is presented:
    - **Throw-off port height (beginning of injection), mm** – [184]
    - **Beginning of injection port diameter, mm** – [185]
    - **Beginning of injection port flow coefficient** – [186]
    - **Throw-off (beginning of injection) groove width, mm** – [187]
- Above needle chamber final charge port is presented:
    - **Open tip delay related to cutting-off port, mm** – [188]
    - **End of injection port diameter, mm** – [189]
    - **End of injection port flow coefficient** – [190]
    - **Above needle chamber charge galleries volume in HP pump, mm^3** – [192]

[Injector] menu

 - hotkey picture.

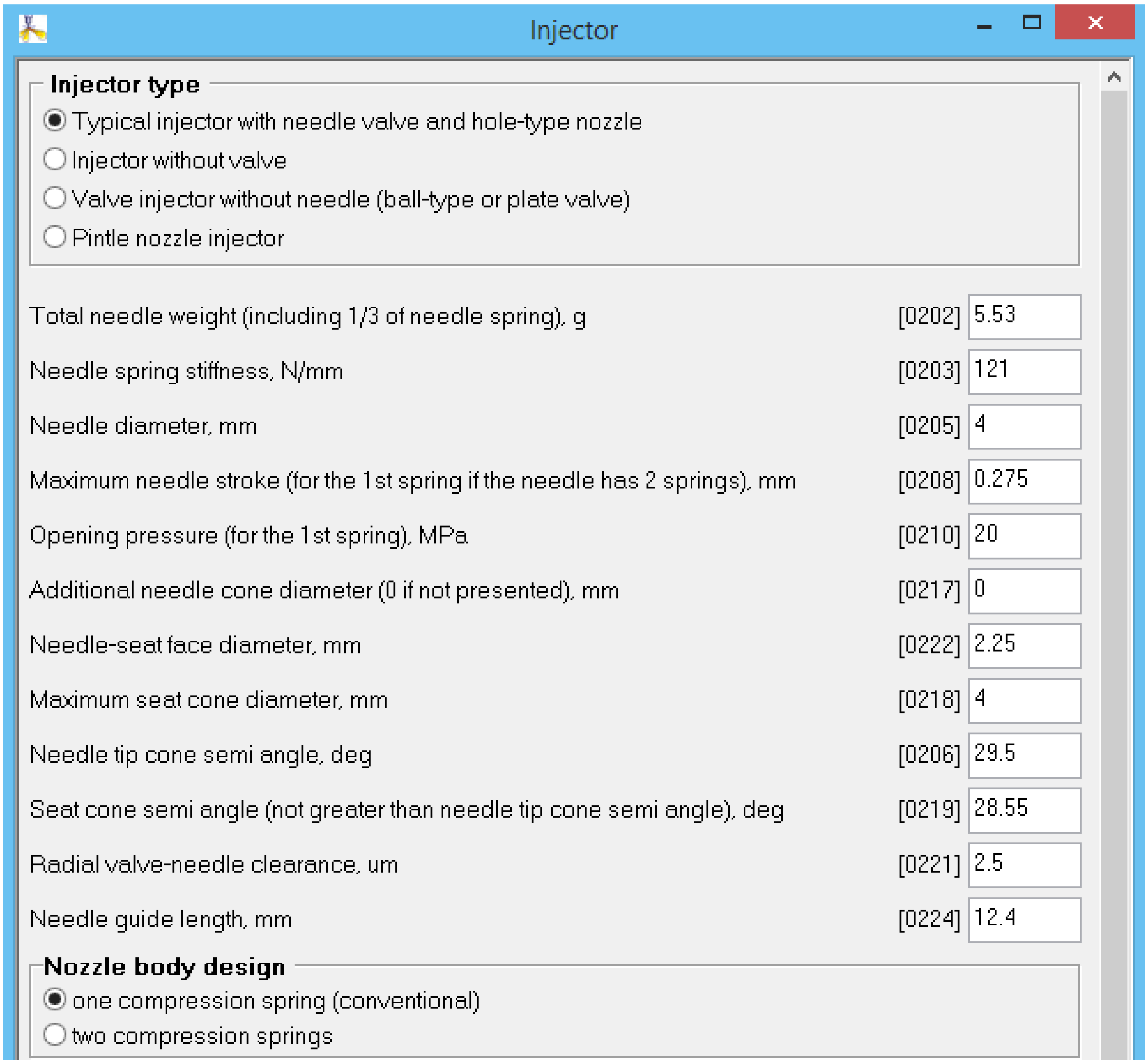


Fig.41 – [Injector] window

Injector type. The following types are available:

- Typical injector with needle valve and hole-type nozzle. Geometricparametersofthisinjectorarepresentedatfig. 42.
- Injector without valve, fig. 43.Not used in contemporary diesel engines.

- Valve injector without needle (ball-type or plate valve), fig. 44.
- Pintlenozzleinjector, fig. 45.

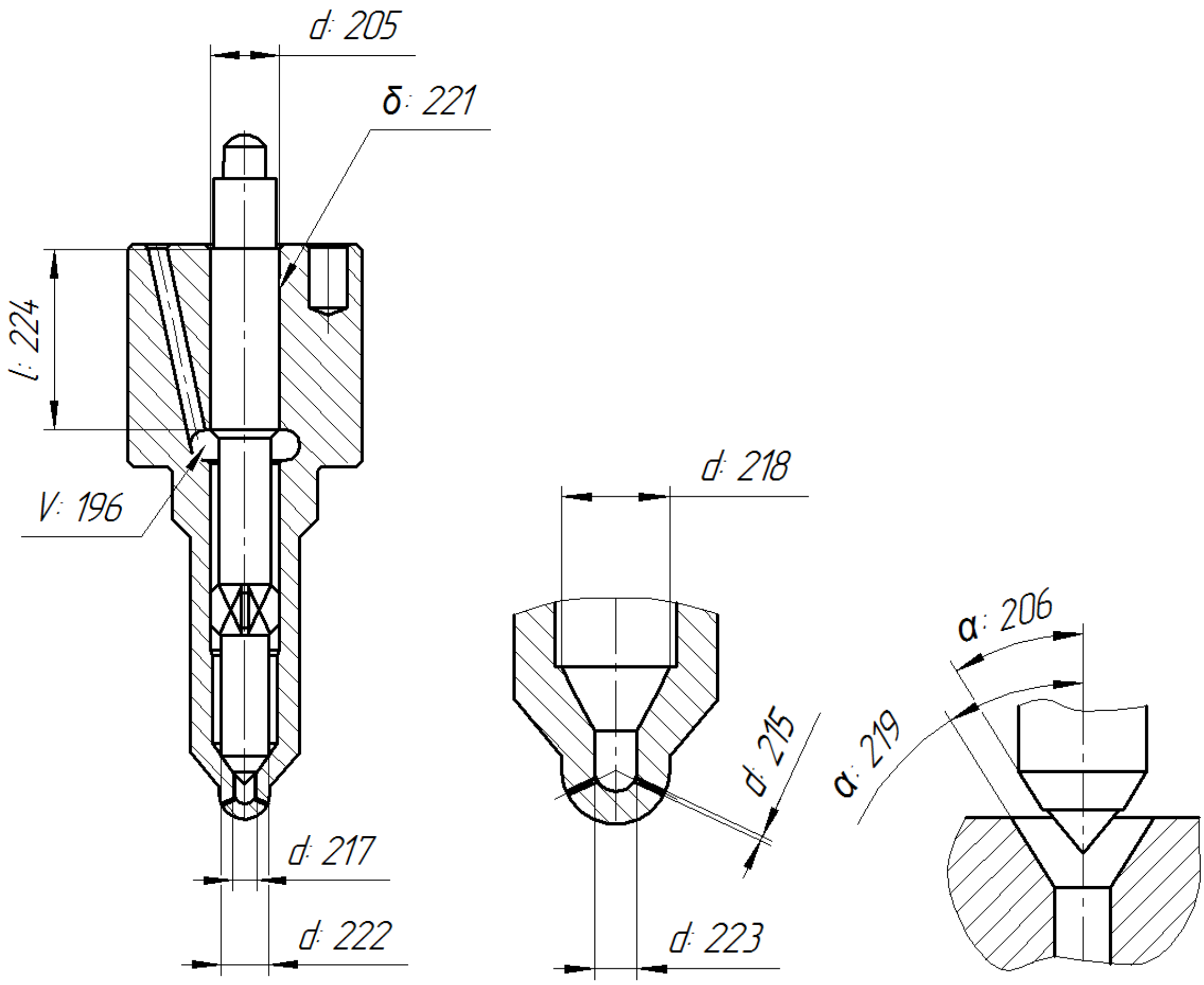


Fig.42 – Typical injector with needle valve and hole-type nozzle

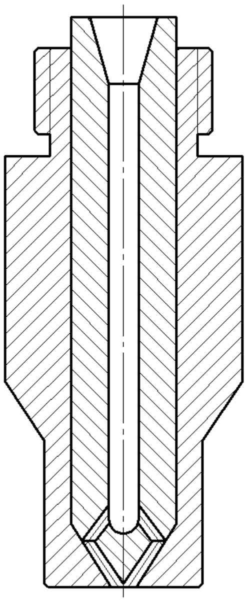


Fig.43 – Injectorwithoutvalve

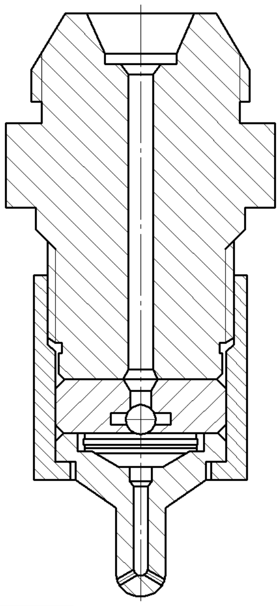


Fig.44 –Valve injector without needle

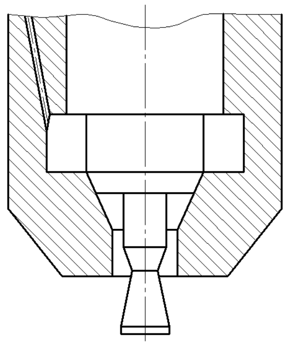


Fig.45 – Pintlenozzleinjector

Itispossibletocalculateinjectorswithtwosprings (fig. 46) with specifying a stiffness ofthe second spring, second phase pressure [211] and additional weight of second spring [212].

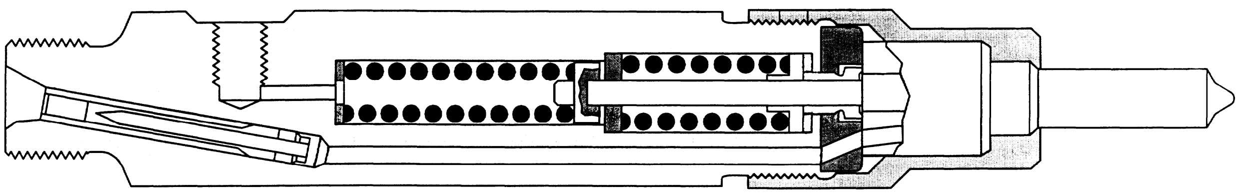


Fig.46 –R. Bosch injector with two springs

Sprayholesmaybeblindholed (fig. 47, a) orsac-less (vco) (fig. 47, b).

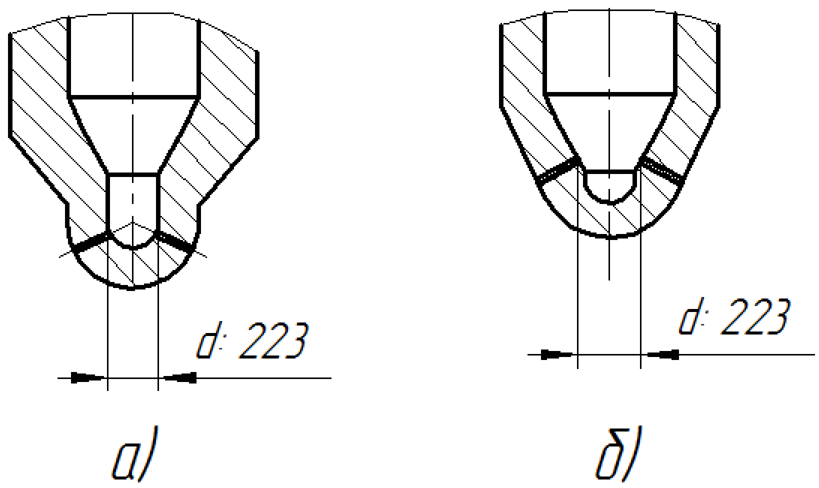


Fig.47 – Sprayholes: a) withblindhole; b) sac-less

Youcanset**areaofsprayholes**bytotalvaluef_c[213], or by numberi_c[214] and diameterd_c [215] of holes (fig. 42, in the middle) that is necessary to calculate droplet mean diameter.

Valve flow coefficient may be estimated the following ways:

- By specifying the constant value[207].
- By V.I. Trusov's empiric formula. Thisformulasetscorrespondence of flow coefficient $\mu_c$from cavitation constant$K=(P_{inj}-P_{avg})/P_{avg}$, seefig. 48.

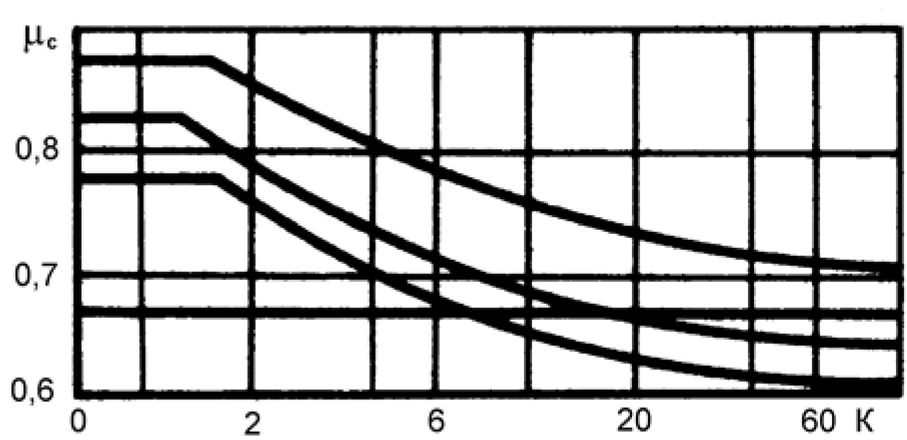


Fig.48 – Correspondence of flow coefficient from cavitation constant

- Using data provided by KolomenskyZavod.

If**pipewithBoschinjectioncharacteristicssensor**is presented, it is necessary to specify it's inside diameter [180] to estimate its influence to the whole process.

It is allowed to calculate the following**injector types**:

- Conventional pressurecontrolled (hydraulicmechanical) injectors when valve is controlled by delivered pressure. In this case it is necessary to setpressure above needle [087]. For conventional systems this pressure is equal to atmospheric(0.1 MPa). Forsystemswithclosedchamberaboveneedle (or increased hydraulic lock pressure)it is necessary to set the desirable value for the beginning of the first calculation cycle.Youcansetin [Operationalconditions…] if you need to adjust this value every cycle.
- Solenoid/piezoelectric valve lift controlled, usually Common Rail (fig. 49).

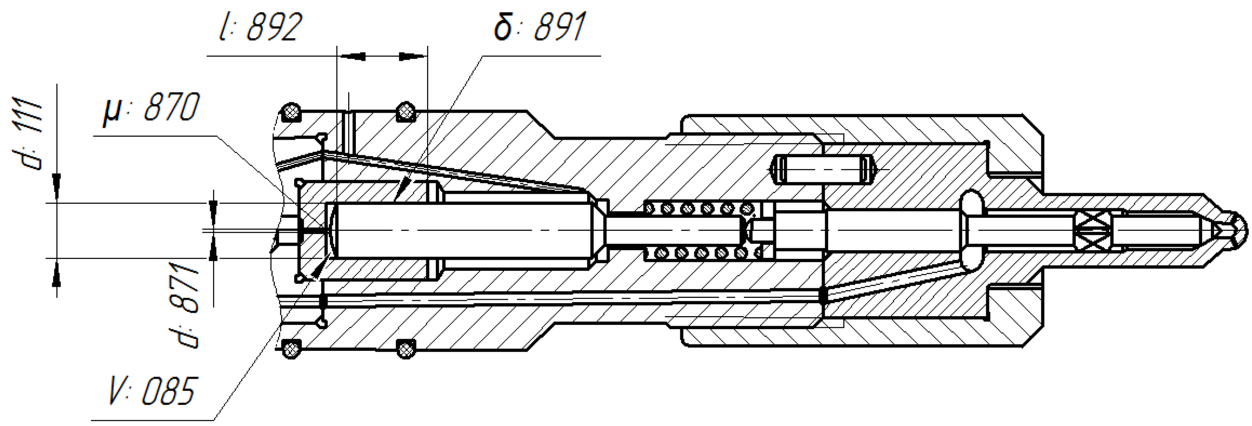


Fig.49 – Solenoidcontrolledinjector

Youshouldsetcontrolchambervolume [085]. If it is no control plunger, this volume is equal to the volume of chamber above needle.Alsoitisnecessarytosetstrain coefficient of this chamber [084] and pressure in chamber (in Common Rail injectors it is equal to HP accumulator pressure).

ForCommonRailinjectors the following features are available

- **Controlplunger (hydrauliclockmultiplier)**(fig. 49) with setting its diameter [111], radial clearance in precision pair [891] and sealing length [892].
- **Controlflowratefeedback**installedon the needle or control piston and closing control gallery during the lift (atfig. 50end face of plunger 6 closes the gallery).

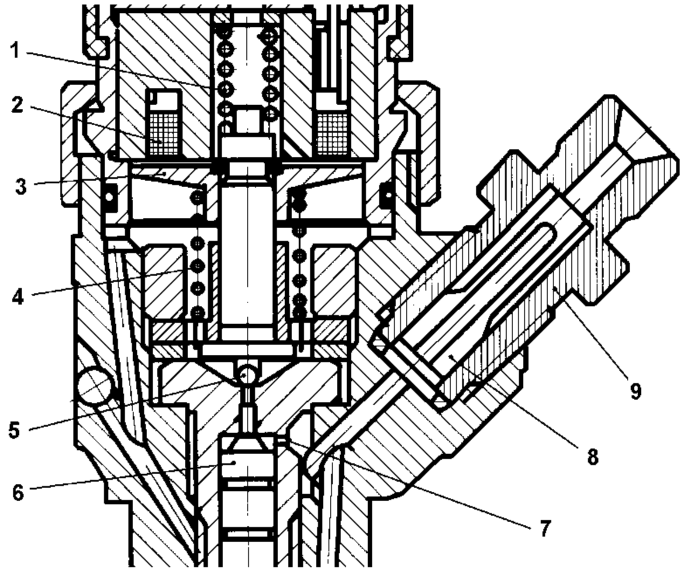


Fig.50 – Control element ofR. Bosch injector. 1 –valvespring; 2 - solenoid; 3 - anchor; 4 –damping spring;
5 - valve; 6 –controlplunger; 7 –orifice of hydraulic control chamber; 8 - filter; 9 – inlet connector

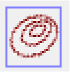
- **Needle and valve stroke feedback as follower drive**.

- Inline solenoid valve injectors, usually for petrol engines.

To increase calculation accuracy it is available to take account to **inlet and outlet resistance**, set effective cross-section of filter [910].

$$P_{тр}^{вх} = P_v - 0{,}25\rho U^2 ; \quad P_{тр}^{вых} = P_v + 0{,}5\rho U^2$$

[Scanning] menu

 - hotkey picture.

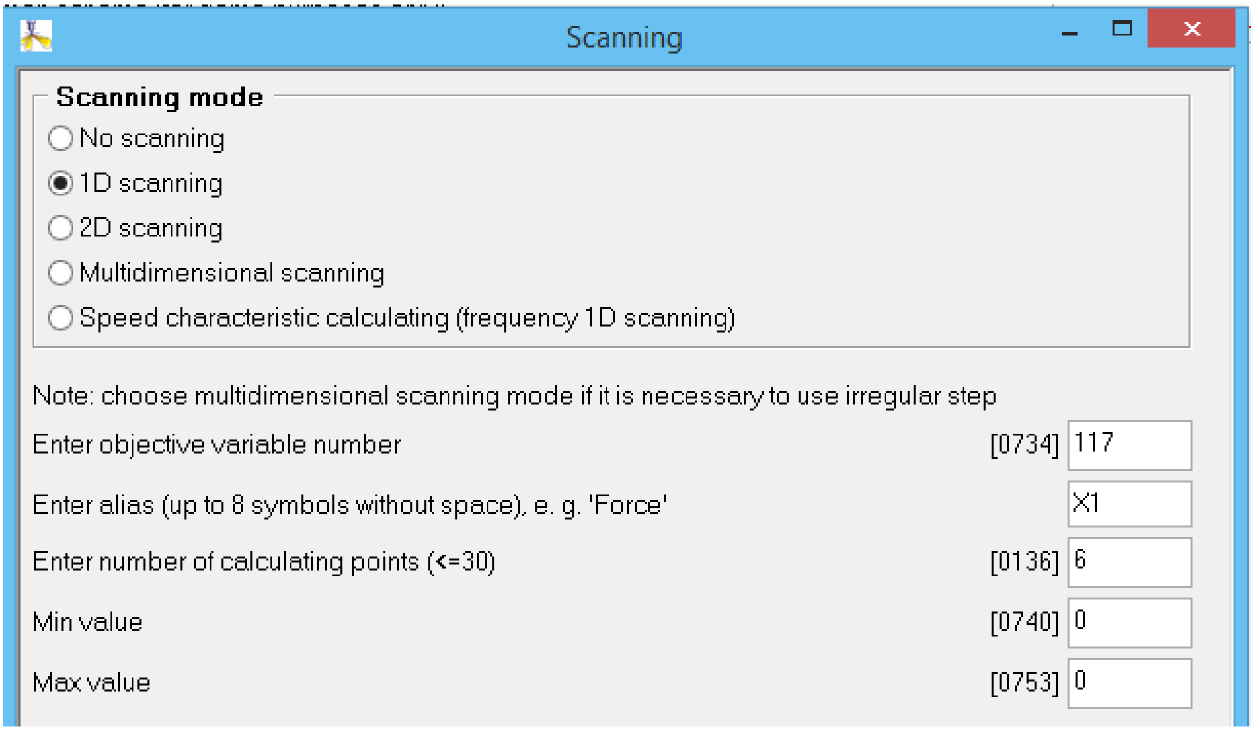


Fig.51 – [Scanning] window

Scanning mode sets number of scanning variables (parameters):

1D scanning means that you select one argument, and changing it in the specified limits, the program determines the dependences of engine parameters on this argument. Results of 1D scanning are displayed as 1D (flat) graphs in the menu item: Results > 1D scanning results.

2D scanning allows to select two arguments, and changing them in the specified limits, the program determines the dependences of engine parameters as functions of two arguments. Results of 2D scanning are displayed as 2D (volumetric) graphs or isoline families in menu item: Results > 2D scanning results.

[Optimization] menu

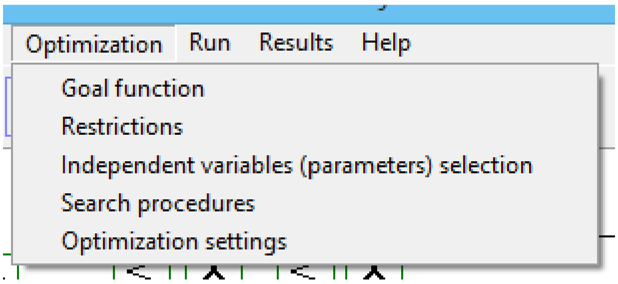


Fig.52 – [Optimization] window

This window is used for optimization problems salvation management.

Formulation of the optimization problem

Goalfunction

Parameters of efficiency of an engine or its separate processes can be included in a goal function:

$$Z_j = Z_j (X_k),$$

which is a function of several variables. The finding of an extremum of a goal function is a problem of optimization.

Vectorofindependentvariables

Set of design parameters of fuel system (goal function minimum should be obtained selecting their values) which form the vector of independent variables X_k, which is in the restricted solutions area:

$$X_{k\,min} < X_k < X_{k\,max}.$$

Restrictions

As a rule, at a searching of optimum combination of fuel system design parameters it is necessary to monitor its thermal and mechanical tensions, emission level and other monitoring factors which limit area of optimum searching and are the restrictions. The restraining parameters, as well as a goal function depend on independent variables:

$$Y_i = Y_i\,(X_k).$$

***

The analytical relation between a goal function both restrictions on the one hand and vector of independent variables on the other hand does not exist, therefore for their calculation the mathematical model of a fuel system is used.

Thus, the problem of optimization of anfuel system is a problem of non-linear programming: a searching of an optimum of a function Z_j at presence of limitations:

$$Y_{i\,min} < Y_i < Y_{i\,max}.$$

The presence of restrictions essentially complicates a solution of optimization problems, therefore it is expedient to reduce a problem of conditional optimization to a problem of non-conditional optimization. The algorithms for non-conditional optimization are much better designed. Method of penal functions is an effective process to take into account the restrictions. The essence of a method is that at violation of restriction, to a minimized goal function the penalty is added. The penalty will increase in accordance with magnification of violation of restriction. Generally the goal function is a sum of three items. EachitemhasitsinfluencecoefficientC_{zj}, C_{yi}, C_{xk}.

$$F = C_{zj} \cdot \overline{Z}_j + \sum_{i=1}^{n} (C_{yi} \cdot \Delta\overline{Y}_i^{\,2}) + \sum_{k=1}^{m} (C_{xk} \cdot \Delta\overline{X}_k^{\,2});$$

where: $\overline{Z}_j = Z_j / Z_{j\_mean}$ - isarelativeparameterZ_j, related to its average value;

$\Delta\overline{Y}_i$ - relative violation of restriction i (relative value of going out the restricted area);

$\Delta\overline{X}_k$ - relative value of going out the restricted area of independent variable k.

At the end of the optimal search process optimal fuel system parameters are put in the standard result files. Searching process is displayed in the protocol (***.opt**file).

[Goal function] menu

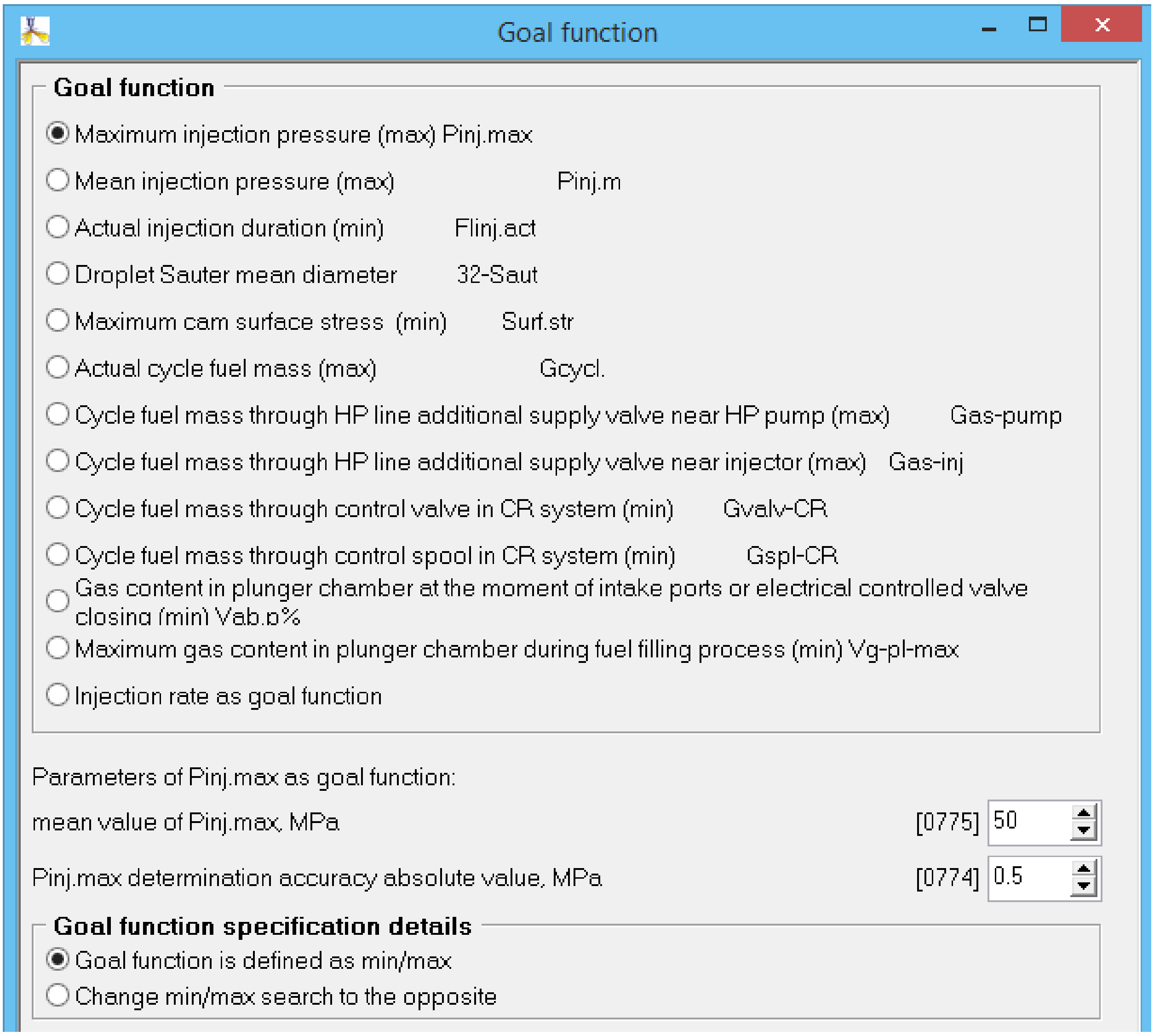


Fig.53 – [Goal function] window

The base of the goal function is an effective fuel system parameter, defining quality of the fuel system under research.

The user should choose any of the fuel system parameters Z_j in the table to be optimized.

[Restrictions] menu

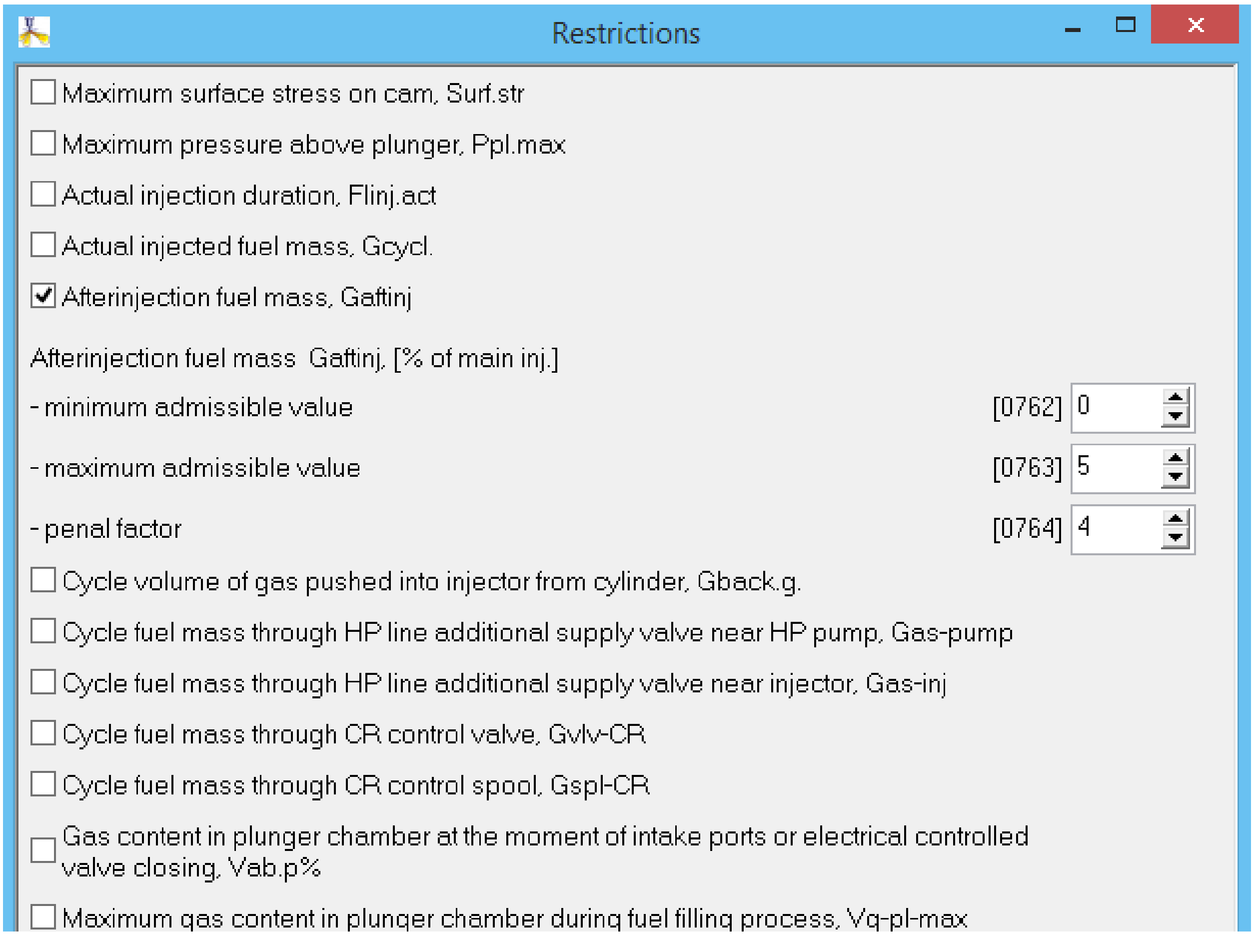


Fig. 54 – [Restrictions] window

This window is used for selection of fuel systemparameters which are involved into the optimal as restrictions Y_i. Set of restrictions can be arbitrary, but the researcher should select only the restrictions which are really important for the current optimization problem.

Each restriction has the following settings:

- Minimalvalue;
- Maximalvalue;
- Penal factor Cyi for leaving permitted area.

In most cases restrictions have one-side effect, i.e. they border the solution area at one side, for example, it it's not allowed to exceed maximal pressure in some volume, and minimal value of pressure does not limit optimum search, because this optimum (for example) is in the high pressure area. Nevertheless, even for one-side restrictions both borders should be set correctly: on the one hand non-actual part of the restriction shouldn't leave the borders during the optimal search, and on the other hand arithmetic mean of the upper border and the lower border should be able for normalization of this restriction (it shouldn't be close to zero). In other words:

The middle of permitted area of border parameter alteration shouldn't be many times more or less than ordinary value.

Penalty coefficients C_{yi} for restrictions should be chosen from the range of 3 - 10. The higher the penalty coefficient is, the steeper is the barrier at the border of permitted area (see fig. 55), on the one hand it makes it impossible to violate the restriction, and on the other hand it makes harder the work of the procedure which produces optimal search on the border of permitted area.

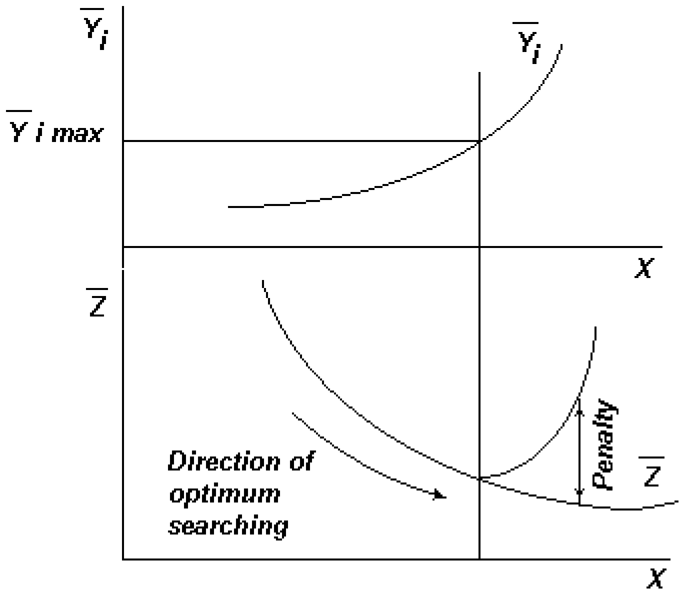


Fig.55 – Penalcoefficients

[Independent variables (parameters) selection] menu

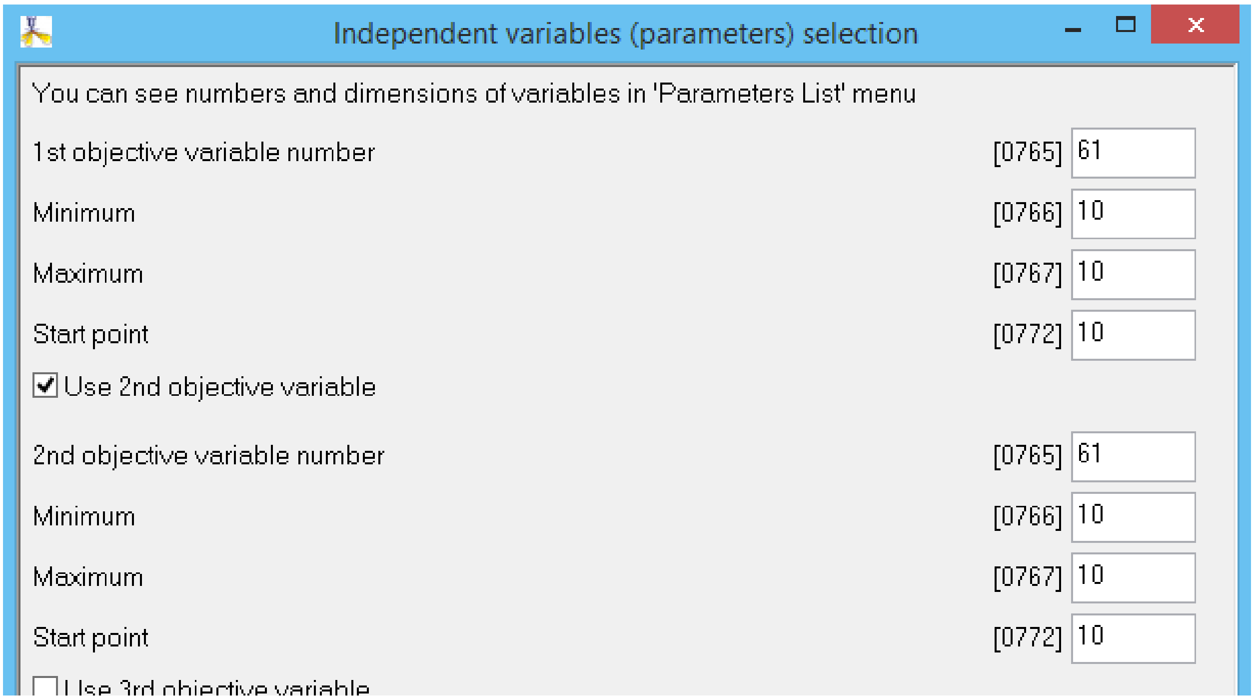


Fig.56 – [Independent variables (parameters) selection] window

This window is used for pointing fuel system parameters which are involved in the optimal search as independent variables (arguments). For each argument has to be given:

- **Number of variable**.
- **Minimum value.**
- **Maximum value.**
- **Start point.**

The least and the greatest values are used to set the solution definition range: if the search procedure tries to leave the specified range, penalty function is added to the goal function, and it increases as much as X_k leaves the range. Penaltycoefficientissetautomatically.

For the search procedures to work effectively, definition range shouldn't be made too large.

To obtain effective solution of an optimization problem with a great number of independent variables, it is recommended to be research different processes independently: divide a problem into smaller sub-problems with their own goal functions, restrictions and sets of independent variables. The less the number of independent variables is, the easier it is to analyze the results of optimal search.

[Search procedures] menu

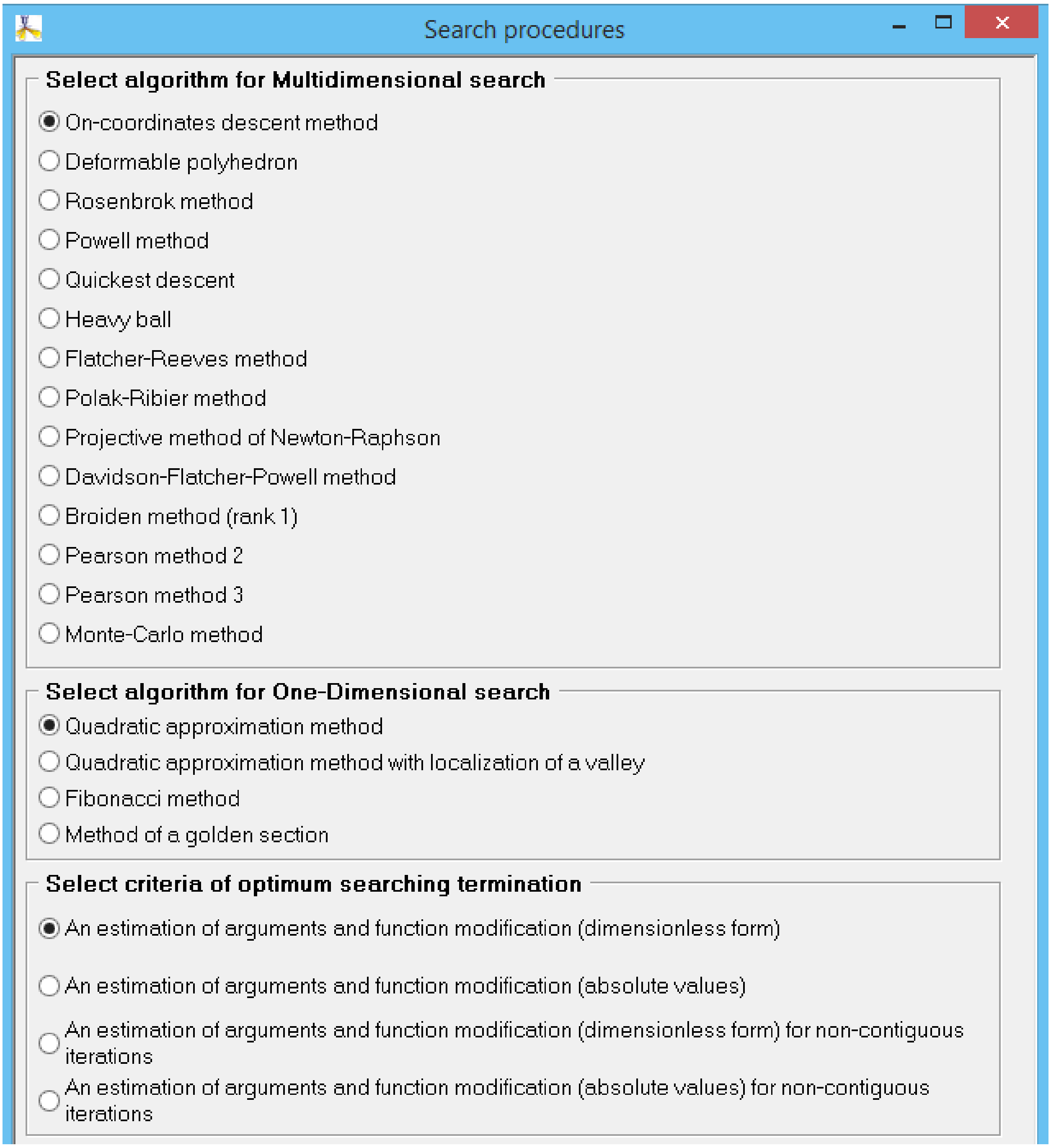


Fig.57 – [Searchprocedures] window

This window contains search algorithms for salvation of non-linear programming problem.

Non-linear programming theory doesn't say which methods are better so while selecting these methods the researcher should be guided by his own experience of optimization problems salvation.

Select algorithm for multidimensional search

- Library contains 14 algorithms:
  - Zero-order methods don't use partial derivatives of goal function:
  - On-coordinates descent method.
  - "Deformable polyhedron" method by Nelder and Mead.
  - Rosenbrok method.
  - Powell method.

- First-order methods use partial derivatives of goal function:
  - "Quickest descent" method.
  - "Heavy ball" method.
  - Fletcher-Reeves method.
  - Polak-Ribier method.
  - Projective method of Newton-Raphson.
  - Davidon-Fletcher-Powell method.
  - Broiden method (rank 1).
  - Pearson method 2.
  - Pearson method 3.

- Random search method:
  - Monte-Carlomethod.

All algorithms allow to find solutions of optimization problems with different efficiency. Developers can only advise to use first-order methods in the cases when expected optimum is far from the starting point. Methods of quickest descent and heavy ball also give good results.

While making the solution more precise, when the starting point is near the solution, it is recommended to use the deformable polyhedron method.

Monte-Carlo method is useful on powerful computers, with prior researches. It is advisable to set a large number of iterations (~1000), and the optimization problem should be posed with a large number of independent variables. Following analysis of optimal search protocol can give interesting solutions in different parts of the definition range. Local optima can be traced, which may then be used as starting points for other procedures.

1D search method selection

Most of the search algorithms search minimum of one-variable function. This procedure makes "steps" in some direction, length of these steps is calculated automatically, direction is determined by the search algorithm. You can select from four well-known procedures:

- Quadratic approximation method.
- Quadratic approximation method with localization of a valley.
- Fibonacci method.
- Method of a golden section.

All these procedures are approximately equivalent, however, because the goal function and the limitations are calculated with some error, methods of Fibonacci and the golden sections give better outcomes.

Optimal search termination criterion selection

Optimal search is terminated when the following conditions are met:

- Alteration of all arguments on some iteration becomes less than some given value.
- Alteration of goal function on some iteration becomes less than some given value.

Estimation of these criteria is produced at the end of each iteration.

Iteration concept differs for each algorithm, but as a whole it is a cyclic order in each direction (with each independent variable), leading to decrease of goal function.

The decision about the termination of process of searching can be accepted at once after completion of following iteration as soon as criterion will be fulfilled. For elimination of probable randomness it is possible to require for the termination of searching the realization of the criteria not only on following iteration, but also on "past" iteration. Criteria check moment selection can be done at the bottom of the window.

Optimal search termination criterion selection:

- An estimation of a modification of arguments and function.
- An estimation of a modification of arguments and function for non-contiguous iterations.

Selecting the latter item increases amount of calculations.

Monte-Carlo method doesn't use the specified criteria for terminating optimal search. This method continues working until goal function calculation resource is exhausted, that's why its value should be set high (500 or more).

[Start computing] menu

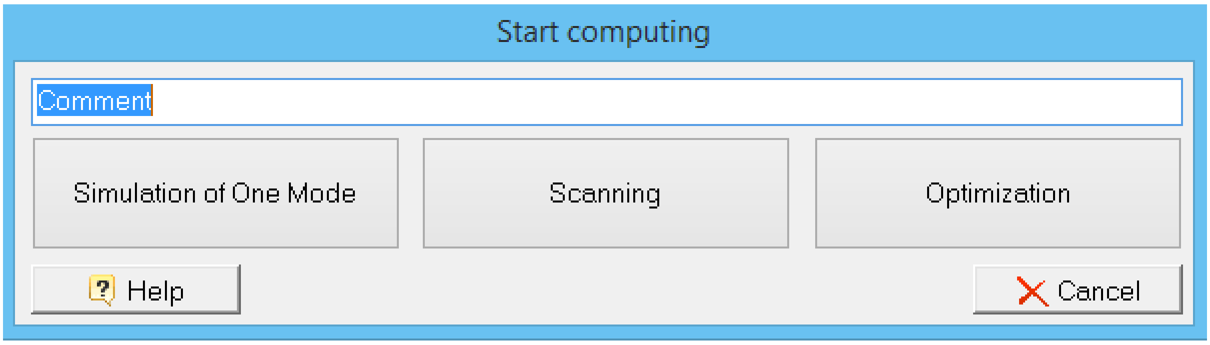


Fig.58 – [Start computing] window

This menu provides several features. If project was not saved it will be suggested.It is necessary to enter project name and select the directory.Thenthewindow (fig. 58) with Comment field and three buttons for selecting calculation type“Simulation of One Mode”, “Scanning”, “Optimization”willappear.

Fig.59 – Normalcalculationcompletion

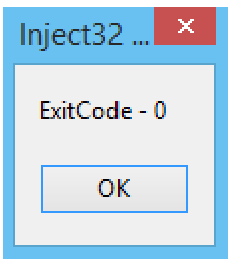


Fig. 60 – Calculationinterrupted (including termination by user). See calculation protocol for information.

When calculation is finished normally or with errors you will see the message (fig.59, 60).

“Comment” fieldshould contain text comment that will be attached to all result files of this calculation.

“SimulationofOneMode” buttonstarts calculation of one mode of the fuel system at one mode. Inadditionalwindowduringthecalculationprocess the calculation protocol will be printed. Aftercalculationiscompletedyoucanfinditat [Results] – [Protocol of computing]. Calculation results will be saved to special files that you can view in [Results] menu.

“Scanning” buttonstartsscanningofthefuelsystemparametersattheselectedmodecorrespondingto [Scanning] menu.Inadditionalwindowduringthescanningprocess the scanning protocol will be printed. Aftercalculationiscompletedyoucanfinditat [Results] – [Protocol of computing]. Scanning results will be saved to special files that you can view in [Results] menu.

“Optimization” buttonstartsoptimization (withallowancetorestrictions) of fuel system parameters within selected parameters range corresponding to [Optimizing] menu settings. Inadditionalwindowduringtheoptimizationprocess the optimization protocol will be printed. Aftercalculationiscompleted,youcanfinditat [Results] – [Protocol of computing]. Optimization results will be saved to special files that you can view in [Results] menu.

[Results] menu

In this menu, you can view calculation results. It is divided to several groups: integral or instant and by selected calculation type.

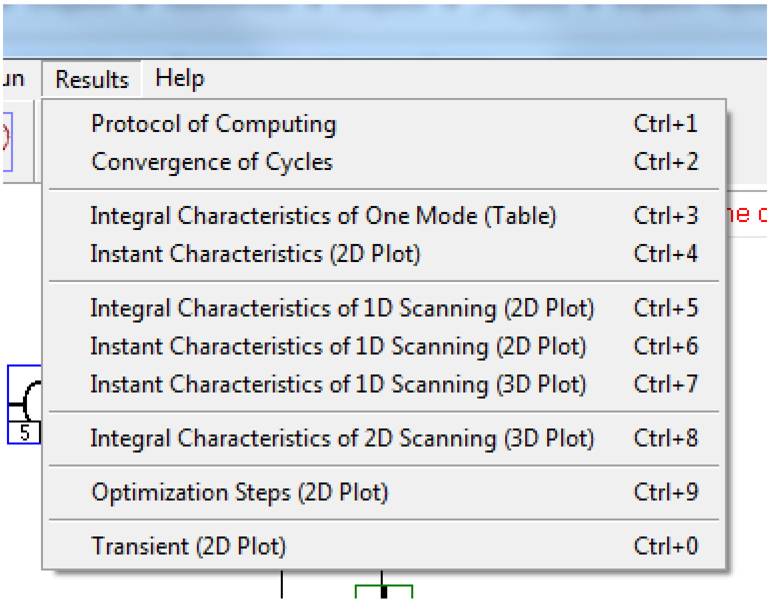


Fig. 61

Each line opens corresponding window:

- "**Protocol of Computing**". This data file (*.pro) is being created during any calculation. In optimization process it is a table with search progress information.
- "**Convergence of Cycles**". Shows convergence parameters cycle by cycle.
- "**Integral Characteristics of One Mode (Table)**" – table with numeric parameters of fuel system in one mode calculation.
- "**Instant Characteristics (2D Plot)**" – 2D plot: dependence of instant parameters from angle (time) in one mode calculation (*.mg2). You

can make some adjustments:

- Trace mode (mouse 3rd button or scroll click);
- Change plots size;
- Changeplotsnumber;
- Show several functions at one plot;
- Load several result files and show its functions on one plot;
- Select argument (right click);
- Movelegend;
- Copy plot (as table) to clipboard;
- Save plot as graphic file.

- "**Integral Characteristics of 1D Scanning (2D Plot)**".
- "**Instant Characteristics of 1D Scanning (2D Plot)**". You can use from 2 to 10 data files (*.mn*).
- "**Instant Characteristics of 1D Scanning (3D Plot)**". Data files type: (*.mg3).
- "**Integral Characteristics of 2D Scanning (3D Plot)**" – (*.in3).
- "**Optimization Steps (2D Plot)**" – (*.opt).
- "**Transient (2DPlot)**" –(*.per).

[Integral Characteristics of One Mode (Table)]

In one mode calculation or optimization process results are presented as a table with integral characteristics and a data file to plot instant characteristics. Integral characteristic is a number that describes a whole injection (or delivery) cycle. It is being saved in *.int data files.

[Instant Characteristics (2D Plot)]

Instant characteristics is a function of camshaft rotation angle (or time). Only one mode calculation or last optimization step results can be presented as 2D plot. You can select available functions using [Parameters] – [Output Data] menu.

Data file type: **.MG2*.

It is possible to create instant characteristics files during scanning process. In this case data files *.MN1, *.MN2, *.MN3, etc. are being created.

[Instant Characteristics of 1D Scanning (3D Plot)]

Results of 1D scanning could be presented as 3D plot in function of 2 variables: angle (or time) and selectable variable.

You can select available functions using [Parameters] – [Output Data] menu.

Data files type: *"*.MG3"*.

[Integral Characteristics of 1D Scanning (2D Plot)]

Data files type: *"*. IN2*".

[Integral Characteristics of 2D Scanning (3D Plot)]

All results of 2D scanning outputs to *.IN3 data files.

[Protocol of Computing]

All text information that you can see during calculation process is saved to this protocol.

Also here you can find all notices, warnings and errors.

All variables are in SI dimensions.

[Convergence of Cycles]

2D plot: dependence of integral characteristics from number of iteration cycle. It is used in convergence analysis.

Data file type: *.uto.

[Transient (2D Plot)]

Fuel system parameters are shown as 2D plot in transient mode calculation. It is dependence of integral characteristics from cycle number or process duration.

Datafilestype: *.per.

[Help] menu

Here you can view this help file, program technical information and the list of used parameters and its numbers.

[Parameters list] menu may be very useful to see a number or a path to any parameter.

Charts editing

This feature provides functionality for table functions.

Itispossibletoeditdataarraybymovingmarkersatthechart (fig. 62).

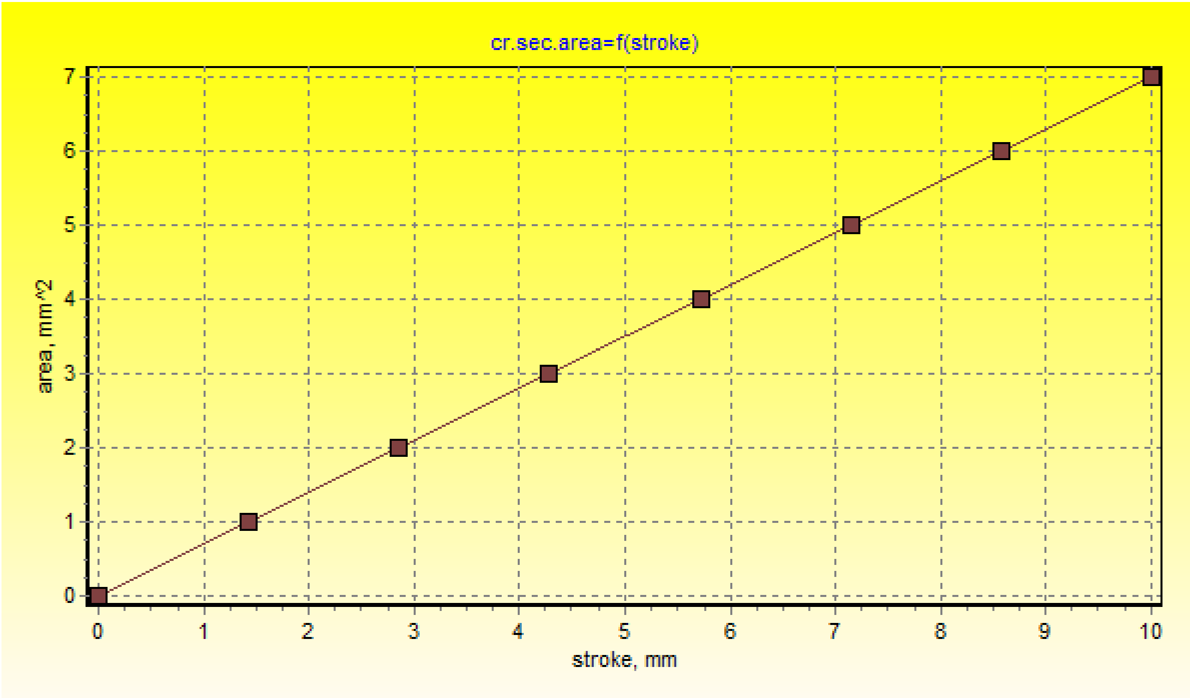


Fig62 – Chartediting

Ifyouclickat the chart by mouse right button the context menu with additional actions will be shown (fig. 63).

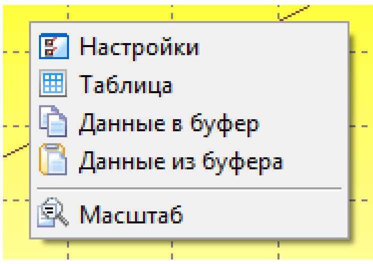


Fig.63 – Context menu with additional actions

- Press Settings to change number of points.
- Press**Table**tosetdataarrayusing keyboard.

- To work with the part of chart using increased scale select desired area with the cursor moving it from left top corner to the right bottom one.Press**Scale** or select any area moving cursor in the opposite direction to restore the scale.
- Bypressing**Datatoclipboard**youcancopytablefunctiontotheclipboardforthefutureworkinexternalprograms.

Bypressing**Datafromclipboard**you can inserts corrected data from keyboard to the chart area.

Contacts

5, 2-nd Baumanskayastr, bld 1

105005 Moscow, Russia

BMSTU, Internal combustion engines dept. (E2)

Prof.Dr. L.V.Grekhov, lgrekhov@mail.ru