

APM Joint

User's Guide

APM Joint

The system for machine element joints calculation and design

Version 15

User's Guide

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Introduction

Preliminaries

APM Joint is the system for machine element joints calculation and design system developed in the Research and Software Development Center APM Ltd.

It allows to perform complex calculation and analysis of most widely used types of joints. With **APM Joint** you can calculate the joints of following types:

- ◆ threaded opened and closed joints, with any element arrangement, arbitrary configuration of surfaces to be joined and arbitrary loading;
- ◆ welded joints with arbitrary arrangement of seams under arbitrary external load, including:
 - ◇ butt joints
 - ◇ tee joints
 - ◇ lap joints
 - ◇ joints produced by spot weld
- ◆ riveted joints of arbitrary arrangement under arbitrary plane loading;
- ◆ joints of rotating elements such as:
 - ◇ interference fits of cylinder and cone shape;
 - ◇ spline and key joints;
 - ◇ radial and axial pins (gluts);
 - ◇ joints with cone rings;
 - ◇ terminal joints;
 - ◇ profile joints;

Hardware and software requirements

The APM Joint system is designed to work in Windows operating systems (MS Windows 7, 8.1, 10 and Microsoft Windows Server 2008 and 2012, respectively). A computer must have two processors (cores) supporting 64-bit addressing. The amount of RAM is 4 GB. The amount of free space on a hard disk is 500 GB. A video card Radeon or Nvidia with hardware support for OpenGL is needed.

Brief guidebook

Introduction (this section) tells you what **APM Joint** is in general and what joint types can be calculated. You will get the requirements to hardware and system software.

Chapter 1, Problems, initial data and results contains detailed description of the problems solved with **APM Joint**. A strict definition of all calculated parameters and initial data is given. Presentation of the results is described.

Chapter 2, Joint editor contains description of the specialized graphics editor that gives user tools for joint geometry specifying and entering of loads, acting on the joint.

Chapter 3, Command reference contains complete description of all commands of the main menu and popup menus for threaded, welded and riveted joints.

Chapter 4, Step by step joint design describes the general scheme of design and calculation.

Chapter 5, Subsystem for cylindrical machine element joint calculation

Fonts used in this book

To help you reading this book we used the following set of fonts

<i>a:\setup</i>	This font represents the text the way it occurs on the screen, and also text, which user should enter with the keyboard
SETUP.EXE	We use all capital letters for the names of files and keys
Help	APM Joint command names and buttons of dialog boxes are shown in boldface
<i>Results</i>	Italics is used for the frame names of dialog boxes and controls

How to contact APM

To contact APM you can use one of the following ways:

Send fax. Our Moscow fax number is +7(498) 600-25-10.

Call by phone +7(498) 600-25-10, +7(495) 514-84-19 (Moscow).

Write a letter and send it to

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Korolev, Moscow Region, 141070, Russia

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internet: www.apmwm.com

Chapter 1. Problems, initial data and results

This chapter consists of two parts and introduction. In the introduction the main features of **APM Joint** are illustrated. In the first part joint parameters that you can calculate in the **APM Joint** are described. For each parameter a strict definition is given. The forms are described in which parameters are calculated and forms they can be looked over by the user as well. In the second part a brief descriptions of calculation method and criterion for each joint type are presented.

Problems and opportunities

APM Joint is intended for machine element joints calculation and design. Using this software you can make all the calculations required for joint design in mechanical engineering. The system allows choosing the most economic solution from a large variety. The calculations are made in form of design and checking one.

Design calculation

The design calculation allows to determine the geometric parameters of joint.

Checking calculation

Safety factors are estimated by checking calculation.

Calculation criteria

The calculation criterion for threaded joints is non-shifting and non-opening of involved surfaces and also static and fatigue strength of joint elements. The welded joints are calculated on the basis of static and fatigue strength conditions; the riveted joint on the basis of strength under constant loading.

Calculation criterion for joints of rotating elements is (depends on the type) non-shifting and non-opening condition of involved surfaces or static and fatigue strength as well as both criteria.

Two methods are used for joint calculation (table 1.1):

1. Calculation according to GOST.
2. Calculation according to SNIP II-23-81*. Steel structures.

Table 1.1 – Calculation standards

<i>GOST, SNIP Threaded opened joint</i>	<i>GOST, SNIP Threaded closed joint</i>	<i>GOST Riveted</i>	<i>– Joint of rotation elements</i>
<i>GOST Butt welding</i>	<i>GOST, SNIP Single-sided welding</i>	<i>GOST, SNIP Double-sided welding</i>	<i>GOST Spot welding</i>

Initial data for joint calculation include joint geometry, external load and parameters that characterize materials, safety ratios, etc.

The list of these parameters according to GOST is given below.

safety factor for crushing 1.1...1.4
 safety factor for shearing 1.1...1.4
 main load coefficient 0.2...0.3
 yield point
 friction coefficient
 material breaking strength

These parameters can be changed in the *General Parameters* dialog box. In the dialog box all these parameters are shown, but enabled are only those that are used for joint of currently selected type. You can use values that are given in the list above. Values for main load coefficient correspond to the case of metal surfaces contact. In Chapter 3 geometry parameters and external loads are described in more details.

Joint type classification

APM Joint let calculate and design following joint types:

- ◆ threaded opened and closed joints, with any element arrangement, arbitrary configuration of surfaces to be joined and arbitrary loading;
- ◆ welded joints with arbitrary arrangement of seams under arbitrary external load, including:
 - ◇ butt joints
 - ◇ tee joints
 - ◇ lap joints
 - ◇ joints produced by spot weld
- ◆ riveted joints of arbitrary arrangement under arbitrary plane loading;
- ◆ joints of rotating elements such as:
 - ◇ interference fits of cylinder and cone shape;
 - ◇ spline and key joints;
 - ◇ radial and axial pins (gluts);
 - ◇ joints with cone rings;
 - ◇ terminal joints;
 - ◇ profile joints;

Dialog box for joint type selection is displayed after program launch (fig. 1.1).

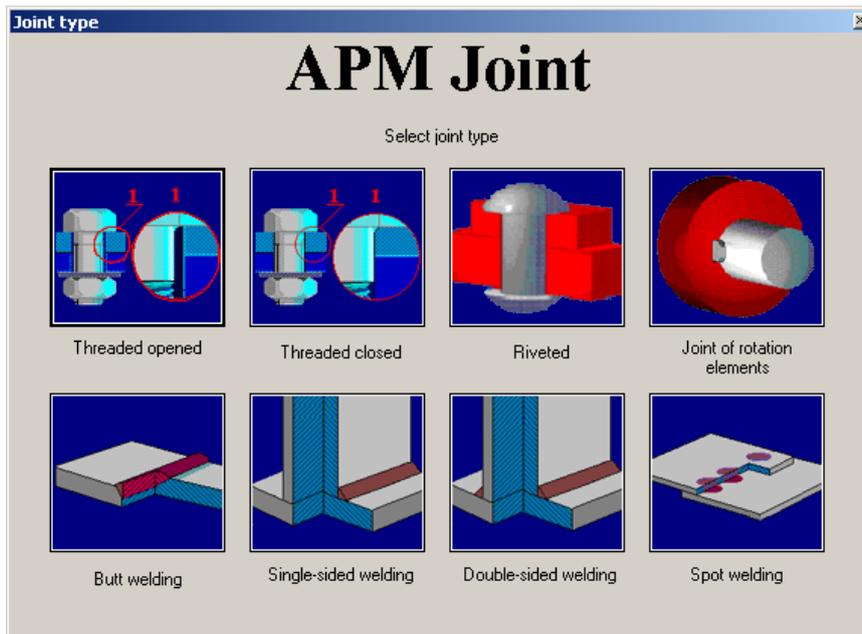


Fig. 1.1 Joint type dialog box

Main types of weld joints are butt weld, corner joint, lap weld, tee weld joint. Corner joint, lap weld and seam tee weld joint have the same calculation principles and can be represented in **APM Joint** by single or double weld seam joint. Spot welding is mostly used for thin sheet parts connection. Recommendations for weld type selection in **APM Joint** are listed in table below.

Table 1.1 – Weld type selection

Weld type	Calculation scheme example	Weld type in APM Joint	Scheme realization in APM Joint editor
Butt		<p>Butt</p>	
Lap		<p>Single-sided</p>	
Corner		<p>Single-sided</p>	
Tee		<p>Single-sided</p>	
		<p>Double-sided</p>	
Spot		<p>Spot</p>	

Specialized graphical editor is used to specify joint geometry, bolts, rivets or spots arrangement, load application for bolt, rivet or weld joint. Editor basic principles are described in chapter 2. Calculation order is listed in chapter 3.

APM Joint rotation elements joint classification is represented in fig. 1.2. Select corresponding button in dialog box (fig. 1.1) to calculate a joint of rotation elements. Further type selection and calculation according to below classification are performed in subsystem of rotation element joints (Chapter 5).

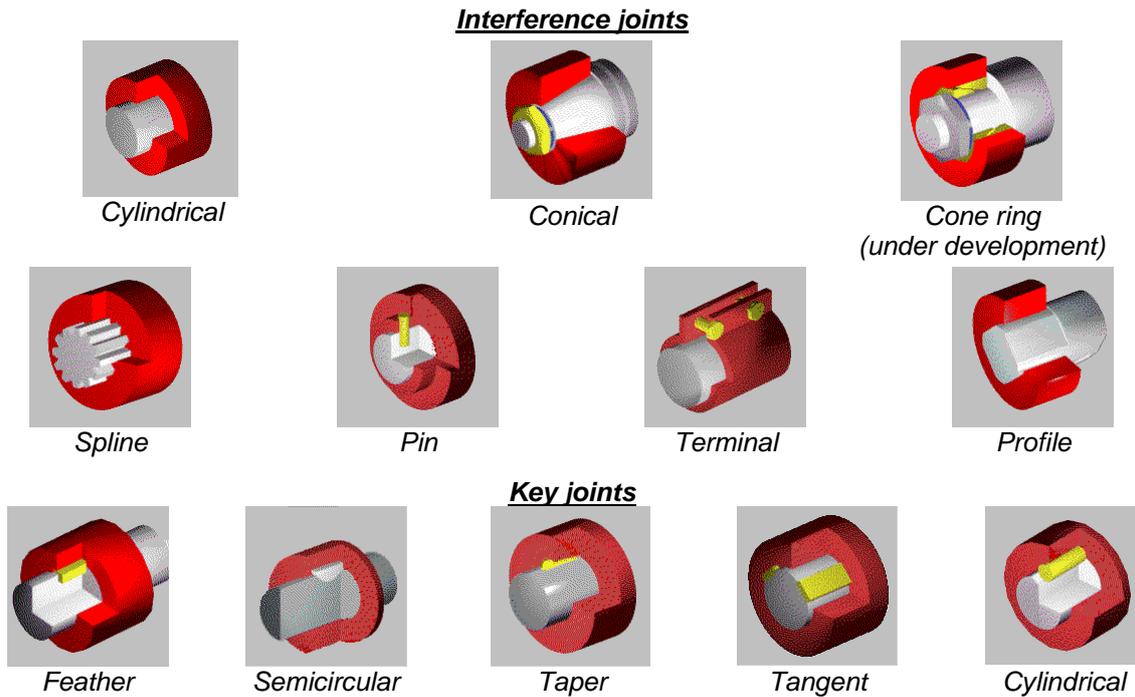


Fig. 1.2 Joint of rotation elements classification in APM Joint

Further we describe initial data, calculation criteria and methods and results for each type of joint.

Threaded joints

Calculation methods and criteria

Criteria for grouped threaded joints depend on bolt mounting (with/without clearance) and on the external load applied. There are two kinds of calculation - for joint non-opening and for non-shifting of the elements being in contact. External loads acting on the flat joint are reduced to the main vector and main moment applied to the center of mass. Threaded joint parameters are determined based on superposition principle. Bolts are calculated for static strength and for fatigue strength under tension. Fatigue strength calculation is performed for variable external load only. If the bolts are mounted without clearance, the criterion used is the strength for shearing and for bearing stress. Calculated bolt loads are displayed as a map of bolt loads and contact pressure is displayed as a specific pressure map. By means of analysis of pressure maps one can determine the probability of breakage of surfaces in contact. Bolt loading maps show the effectiveness of bolt usage.

Initial data

Bolt joint with clearance	Bolt joint without clearance
Design calculation	
1. <i>Butt contour geometry</i>	
2. <i>External loads, [N]:</i> 2.1. <i>shear forces;</i> 2.2. <i>normal forces.</i> 3. <i>Constant parameters (GOST):</i> 3.1. <i>unopening safety factor;</i> 3.2. <i>shear safety factor;</i> 3.3. <i>main load factor;</i> 3.4. <i>yield safety factor of connected parts;</i> 3.5. <i>yield point of connected parts, [MPa];</i> 3.6. <i>breaking strength of connected part material, [MPa].</i> 3.7. <i>number of shear / friction surfaces.</i>	2. <i>External loads, [N]:</i> 2.1. <i>shear forces</i> 2.2. <i>–</i> 3. <i>Constant parameters (GOST):</i> 3.1. <i>–</i> 3.2. <i>–</i> 3.3. <i>–</i> 3.4. <i>–</i> 3.5. <i>yield point of connected parts, [MPa];</i> 3.6. <i>–</i> 3.7. <i>number of shear / friction surfaces.</i>

<p>4. <i>Constant parameters (SNIP):</i></p> <p>4.1. <i>design shear strength of joint, [MPa];</i></p> <p>4.2. <i>design bearing strength of joint, [MPa];</i></p> <p>4.3. <i>design tensile strength of bolt, [MPa];</i></p> <p>4.4. <i>coefficient of working conditions;</i></p> <p>4.5. <i>safety factor;</i></p> <p>4.6. <i>friction coefficient;</i></p> <p>4.7. <i>number of shear / friction surfaces.</i></p>	<p>4. <i>Constant parameters (SNIP):</i></p> <p>4.1. <i>design shear strength of joint, [MPa];</i></p> <p>4.2. <i>design bearing strength of joint, [MPa];</i></p> <p>4.3. <i>design tensile strength of bolt, [MPa];</i></p> <p>4.4. <i>coefficient of working conditions;</i></p> <p>4.5. <i>safety factor;</i></p> <p>4.6. <i>friction coefficient;</i></p> <p>4.7. <i>number of shear / friction surfaces.</i></p>
Checking calculation	
<p>1-3 see design calculation</p> <p>4. <i>Additional parameters:</i></p> <p>4.1 <i>Bolt diameter.</i></p>	

Results

Definition

Principal central axes are two mutually perpendicular axes passing through the center of mass, around which the axial inertia moments having maximal values (mixed/product moment equal to zero).

Bolt joint with clearance	Bolt joint without clearance
Design calculation	
<p>1. <i>Butt surface area, [mm²].</i></p> <p>2. <i>X coordinate of butt center of mass, [mm].</i></p> <p>3. <i>Y coordinate of butt center of mass, [mm].</i></p> <p>4. <i>Moments of inertia around central axes:</i></p> <p>4.1. <i>around horizontal X axis, [mm⁴];</i></p> <p>4.2. <i>around vertical Y axis, [mm⁴].</i></p> <p>5. <i>The slopes of principal central axes, [deg].</i></p> <p>6. <i>X coordinate of bolt mass center, [mm].</i></p> <p>7. <i>Y coordinate of bolt mass center, [mm].</i></p>	
<p>8. <i>Bolt tightening force, [N].</i></p> <p>9. <i>Maximum load on bolt, [N].</i></p> <p>10. <i>Maximum pressure on contact surface, [MPa].</i></p> <p>11. <i>Bolt diameter - external diameter of the bolt, [mm].</i></p> <p>12. <i>Tightening torque, [N*m].</i></p> <p>13. <i>Friction torque in thread, [N*m].</i></p> <p>14. <i>Friction torque in nut flank, [N*m].</i></p>	<p>8. <i>Bolt diameter, [mm].</i></p> <p>9. <i>Maximum shear load on bolt, [N].</i></p> <p>10. <i>Minimum plate thickness, [mm] – acting bearing stresses are equal to allowable ones by this thickness</i></p>

Checking calculation

<p>1-14 see design calculation</p> <p>Fatigue safety factor — the ratio of allowable loading cycles number to the real cycles number (GOST).</p> <p>Strength safety factor — ratio of the bolt material breaking strength to actual stress of most loaded bolt (GOST).</p> <p>Strength safety factor — ratio of the bolt material design strength to actual stress of most loaded bolt (SNIP).</p>	<p>1-10 see design calculation</p> <p>Shearing strength safety factor — ratio of the bolt material shear strength (GOST) / design shear strength (SNIP) to actual stress of most loaded bolt.</p>
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The pressure in contact area is presented as a pressure map.

Riveted joints

Calculation methods and criteria

Rivets are calculated on shear and bearing strength under loads acting in a contact area plane. Shear forces on rivets are represented as a load map and give an estimate of effectiveness of its usage and arrangement.

Initial data

Design calculation

1. Joint contact area geometry and rivets position.
2. External loads:
 - 2.1. shear forces.
3. Parameters:
 - 3.1. Yield point of connected parts material, [MPa].
 - 3.2. Number of shear / friction surfaces.

Checking calculation

- 1-3 see design calculation
4. Additional parameters:
 - 4.1. Rivet diameter.

Results

Design calculation

1. Butt surface area, [mm²].
2. X coordinate of butt center of mass, [mm].
3. Y coordinate of butt center of mass, [mm].
4. Moments of inertia around central axes:
 - 4.1. around horizontal X axis, [mm⁴];
 - 4.2. around vertical Y axis, [mm⁴].
5. The slopes of principal central axes, [deg].
6. Rivet diameter, [mm] — Rivet pivot diameter (without accounting of inner hole). If there is an inner hole then calculation must be performed under condition of the cross section area equivalence.
7. Maximum shear force on rivet [N] — the load applied to the most loaded rivet and acting in the contact area plane.
8. Minimum plate thickness, [mm] – minimum plate thickness, such that actual crush (bearing) stress is equal to permissible one.

Checking calculation

1-8 see design calculation

Shear safety factor – ratio of the bolt material allowable shear stress to actual stress of most loaded rivet.

Welded joints

Calculation methods and criteria

Static strength of the butt-welding is determined by finite element method. Besides nominal stresses, local ones are calculated that act in the areas of stress concentration. These local stresses are used for fatigue strength calculation. In this case checking calculation comes to the determination of safety ratio for static and fatigue strength.

For corner weld calculation the methods of polar and axial moment of inertia are used. The calculation comes to leg determination. For strength calculation are used the equivalent stresses that are determined on the base of energy theory of strength. When checking calculation is performed, the deformed state of welded seams is calculated with finite element method; it comes to the determination of safety ratio for static and fatigue strength.

Besides this, for the purposes of complete analysis, the deformed state is displayed as colored maps. Using this map one can find the areas of welded seam that possess small stresses and, if necessary, to change the seam geometry in order to get configuration of uniform strength.

Butt welding

Initial data

Design calculation

1. *Butt surface geometry.*
2. *External loads:*
 - 2.1. *normal forces.*
 - 2.2. *shear forces*
3. *Parameters:*
 - 3.1. *Yield point of connected parts material, [MPa];*
 - 3.2. *Breaking point of connected parts material, [MPa].*
 - 3.3. *Number of shear / friction surfaces.*

Checking calculation

- 1-3 *see design calculation*
4. *Additional parameters:*
 - 4.1. *Effective stress concentration factor.*

Results

Design calculation

1. *Butt surface area, [mm²].*
2. *X coordinate of butt center of mass, [mm].*
3. *Y coordinate of butt center of mass, [mm].*
4. *Moments of inertia around central axes:*
 - 4.1. *around horizontal X axis, [mm⁴].*
 - 4.2. *around vertical Y axis, [mm⁴].*
5. *The slopes of principal central axes, [deg].*
6. *Maximum effective stress acting in a butt.*
7. *Static strength safety factor.*

Checking calculation

- 1-7 *See design calculation*
8. *Endurance safety factor.*

Butt stresses are displayed as a stress map.

Single and double sided welding

Initial data

Design calculation

1. *Weld seam geometry. (Can be discrete).*
2. *External loads:*
 - 2.1. *normal forces;*
 - 2.2. *shear forces.*
3. *Constant parameters (GOST):*
 - 3.1. *Yield safety factor for connected parts, [MPa]*
 - 3.2. *Yield point of connected parts material, [MPa].*
 - 3.3. *Number of shear / friction surfaces.*
4. *Constant parameters (SNIP):*
 - 4.1. *Design shear strength of weld seam, [MPa]*
 - 4.2. *Design shear strength of weld seam boundary, [MPa]*
 - 4.3. *Depth factor of seam penetration*
 - 4.4. *Depth factor of seam boundary penetration*
 - 4.5. *Coefficient of seam working conditions f*
 - 4.6. *Coefficient of seam working conditions z*

4.7. Coefficient of joint working conditions

Checking calculation

1-3 see design calculation

4. Additional parameters:

4.1. Leg, [mm];

4.2. Effective stress concentration factor.

Results

Design calculation

1. Seam area in weak section, [mm²].
2. X coordinate of seam center of mass, [mm].
3. Y coordinate of seam center of mass, [mm].
4. Seam moments of inertia around central axes:
 - 4.1. around horizontal X axis, [mm⁴].
 - 4.2. around vertical Y axis, [mm⁴].
5. The slopes of principal central axes, [deg].
6. Maximum shear stress, [MPa] – maximum shear stress acting in a weld seam.
7. Leg, [mm] – this value let select required electrode.

Checking calculation

1-7 see design calculation

8. Strength safety factor (GOST).

9. Safety factor (SNIP).

10. Endurance safety factor (GOST).

Stress distribution in weld seam is displayed as a stress map.

Spot welding

Initial data

Design calculation

1. Spot arrangement.
2. External loads:
 - 2.1. shear forces.
3. Parameters:
 - 3.1. Yield point of spot material, [MPa].

Checking calculation

1-3 see design calculation

4. Additional parameters:

4.1. Spot diameter, [mm].

4.2. Effective stress concentration factor.

Results

Design calculation

1. X coordinate of spots center of mass, [mm].
2. Y coordinate of spots center of mass, [mm].
3. Spots moments of inertia around central axes:
 - 3.1. around horizontal X axis, [mm⁴].
 - 3.2. around vertical Y axis, [mm⁴].
4. Spot diameter, [mm].

Checking calculation

1-4 see design calculation

3. Fatigue safety factor.

Yield safety factor for shear- ratio of the spot material yield point to actual stress of most loaded spot

Stress in spots is displayed as a stress map.

Maximum effective stress - the stress acting in the most loaded seam point. The equivalent stress is the tensional stress that causes the same breaking action as both normal and tangent stresses.

Leg - geometry parameter of the seam cross-section that is look like isosceles rectangular triangle. The leg value let you to determine corresponding electrode diameter.

Rotation element joints

Calculation methods and criteria

Calculation of those joints we describe briefly, since they are discussed in many books.

For preloaded joints the solution of Lame problem is used.

For other joints we use the equality of external loads and internal loads.

Criterion for rotating machine elements joint calculation depends on joint type. One of the following criteria is used

Safety ratio for joint non-opening or safety ratio for shearing

Safety ratio for static strength or fatigue joint

Cylindrical press-fitted joints

Initial data	Results
<ol style="list-style-type: none"> 1. Geometry <ol style="list-style-type: none"> 1.1. Shaft diameter, [mm]. 1.2. Shaft hole diameter, [mm]. 1.3. External diameter of hub, [mm]. 1.4. Joint length, [mm]. 2. Working condition <ol style="list-style-type: none"> 2.1. Torque, [N*m]. 2.2. Bending moment, [N*m]. 2.3. Axial force, [N]. 2.4. Radial force, [N]. 3. Shaft-hub friction coefficient 4. Materials <ol style="list-style-type: none"> 4.1. Shaft (selection from database). 4.2. Hub (selection from database). 5. Surface roughness (Ra) <ol style="list-style-type: none"> 5.1. Shaft, [mkm]. 5.2. Hub, [mkm]. 6. System of fit (shaft system, hole system, all possible) 	<ol style="list-style-type: none"> 1. Minimum required interference from nonopening/nonshifting condition. 2. Maximum allowable interference from contact strength condition of joint parts. 3. List of possible fits from database. Following parameters are calculated for each fits: <ol style="list-style-type: none"> 3.1. Maximum / minimum interference, [mkm] 3.2. Maximum / minimum pressing force, [N].

Conical press-fitted joints

Initial data	Results
<ol style="list-style-type: none"> 1. Geometry <ol style="list-style-type: none"> 1.1. Shaft diameter, [mm]. 1.2. Cone angle, [deg]. 1.3. External diameter of hub, [mm]. 1.4. Joint length, [mm]. 2. Working condition <ol style="list-style-type: none"> 2.1. Torque, [N*m]. 2.2. Bending moment, [N*m]. 2.3. Radial force, [N]. 3. Shaft-hub friction coefficient 4. Materials 	<ol style="list-style-type: none"> 1. Yield safety factor <ol style="list-style-type: none"> 1.1. Shaft 1.2. Hub 2. Required tightening force, [kN]. 3. Maximum tightening force, [kN]. 4. Diametrical interference, [mm]. 5. Axial displacement (interference), [mm].

<ul style="list-style-type: none"> 4.1. Shaft (selection from database). 4.2. Hub (selection from database). 5. Surface roughness (Ra) <ul style="list-style-type: none"> 5.1. Shaft, [mkm]. 5.2. Hub, [mkm]. 	
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Spine joints

Initial data	Results
<p style="text-align: center;">Main data</p> <ul style="list-style-type: none"> 1. Shaft diameter, [mm]. 2. Torque, [N*m]. 3. Thermal treatment <ul style="list-style-type: none"> 3.1. Shaft (martempering, hardening, carburizing, nitriding). 3.2. Hub (martempering, hardening, carburizing, nitriding). 4. Load type (constant, pulsating, alternating). 5. Assembly type (immovable, movable) 6. Spline type (straight-sided, involute, triangular) <p style="text-align: center;">Additional parameters</p> <ul style="list-style-type: none"> 1. Allowable bearing stress, [MPa] 	<ul style="list-style-type: none"> 1. Required joint length. 2. Spline subtype. 3. Root diameter of spline, [mm]. 4. Teeth number. 5. External diameter of spline, [mm]. 6. Spline tooth width, [mm]. 7. Centering diameter, [mm]. 8. Minimum width of base surface, [mm]. 9. Chamfer, [mm]. 10. Fillet radius, [mm].

Required spline is selected from APM Mechanical database depending on current standard.

Database path to the spline tables: **Standard – Parts – Splines.**

Pin joints

Initial data	Results
<p style="text-align: center;">Main data</p> <ul style="list-style-type: none"> 1. Shaft diameter, [mm]. 2. Torque, [N*m]. 3. Axial force, [N]. 4. Axis angle, [deg]. 5. Pin number. 6. Materials <ul style="list-style-type: none"> 6.1. Shaft (select from database). 6.2. Pin (select from database). 6.3. Hub (select from database). 7. Load type (constant, pulsating, alternating). <p style="text-align: center;">Additional parameters</p> <ul style="list-style-type: none"> 1. Allowable shear stress, [MPa] 	<ul style="list-style-type: none"> 1. Pin diameter, [mm]. 2. Allowable shear stress, [MPa]. 3. Acting shear stress, [MPa].

Terminal joint

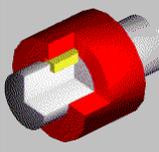
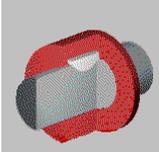
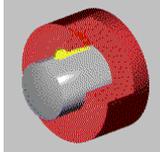
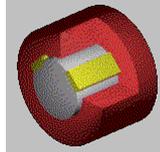
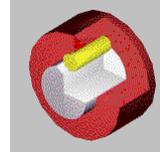
Initial data	Results
<ul style="list-style-type: none"> 1. Geometry <ul style="list-style-type: none"> 1.1. Shaft diameter, [mm]. 1.2. Screw number. 1.3. Contact area length, [mm]. 2. Working condition <ul style="list-style-type: none"> 2.1. Torque, [N*m]. 2.2. Axial force, [N]. 2.3. Friction coefficient, [-]. 3. Screw material (select from database). 	<ul style="list-style-type: none"> 1. Screw diameter, [mm]. 2. Allowable stress, [MPa]. 3. Acting stress, [MPa]. 4. Tighting force, [N]

Profile joints

Initial data	Results
<p style="text-align: center;">Main data</p> <ol style="list-style-type: none"> 1. Shaft diameter, [mm]. 2. Torque, [N*m]. 3. Number of sides 4. Side width, [mm]. 5. Materials <ol style="list-style-type: none"> 5.1. Shaft (selection from database). 5.2. Hub (selection from database). 6. Load type (constant, pulsating, alternating). <p style="text-align: center;">Additional parameters</p> <ol style="list-style-type: none"> 1. Allowable bearing stress, [MPa] 	<ol style="list-style-type: none"> 1. Required joint length, [mm]. 2. Allowable bearing stress, [MPa]. 3. Acting bearing stress, [Mpa].

Key joints

Table 1.2 – Key joint initial data and results

Key types				
				
Feather	Semicircular	Taper	Tangent	Cylindrical
Initial data				
Main data				
<ol style="list-style-type: none"> 1. Shaft diameter, [mm]. 2. Torque, [N*m]. 3. Load type (constant, pulsating, alternating). 4. Shaft material (selection from database). 5. Key material (selection from database). 6. Hub material (selection from database). 				
7 Assembly type (unmovable, movable)		7. Friction coefficient.		7. Pin diameter, [mm].
		–	8 Key width, [mm].	8. Key number.
Additional parameters				
1. Allowable bearing stress, [MPa]				
2. Allowable shear stress, [MPa].		–		Allowable shear stress, [MPa]
Results				
<ol style="list-style-type: none"> 1. Key width, [mm]. 2. Key height, [mm]. 3. Key groove height on shaft, [mm]. 4. Key groove height on hub, [mm]. 5. Key length, [mm]. 6. Allowable bearing stress, [MPa]. 7. Acting bearing stress, [MPa]. 				<ol style="list-style-type: none"> 1. Key length, [mm]. 2. Allowable bearing stress, [MPa] 3. Acting bearing stress, [MPa].

-	<p>8. Allowable shear stress, [MPa].</p> <p>9. Acting shear stress, [MPa].</p>	-	<p>4. Allowable shear stress, [MPa].</p> <p>5. Acting shear stress, [MPa].</p>
---	--	---	--

Required key is selected from APM Mechanical database depending on current standard.
 Database path to the key tables: **Standard – Parts – Keys.**

Chapter 2. Joint Editor

APM Joint uses **APM Graph** with some extra functionality as a joint editor. The description of **APM Graph** features as joint editor is resulted in this chapter. The detailed description of APM Graph is represented in APM Graph user's guide.

Editor components

General view of joint editor is shown below. It components are toolbar, status line, rulers and main window (working field).

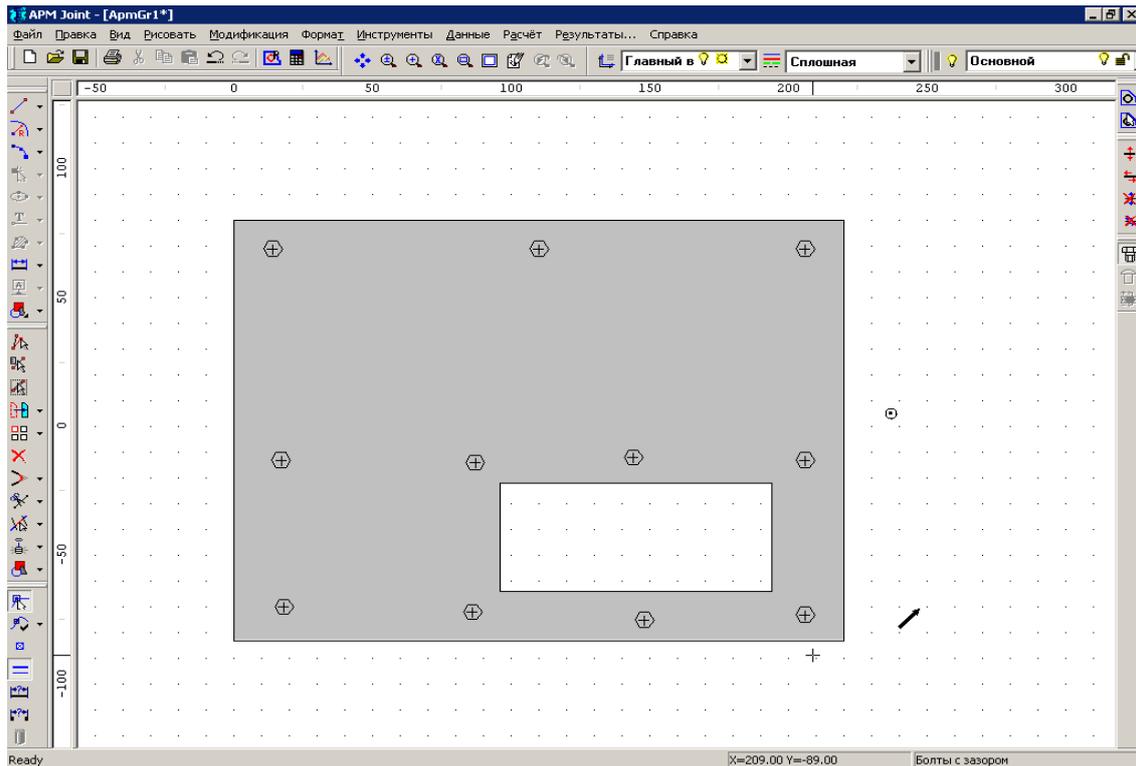


Fig. 2.1 APM Joint external interface

Working field

The working field is the main component of Joint editor. It is used to draw joint geometry, loads, bolts, etc.

Rulers

The editor includes two rulers - vertical and horizontal. Scales are shown on rulers. Scales depend on current drawing scale in the editor window.

Scrolling/Scaling

To scroll view, hold right mouse button and move the mouse.

To scale view dynamically in scaling mode press left mouse button and drag the mouse upward or downward. You can use mouse wheel for view scaling. Holding scroll button will allow you to move the image within the limits of the working window.

By pressing the right mouse button action depends on active command. The right mouse button pressing cancels last action for many commands. For other commands the right mouse button pressing enables the dialog boxes for input of operation parameters from the keyboard.

Toolbars

Toolbars contains buttons of the editor commands. For enabling of the necessary command, click the left mouse button on corresponding button. The description of main menu commands and corresponding buttons of toolbars are presented in chapter 3.

View / Toolbars command enables dialog box that allows you to toggle toolbars on and off.

APM Joint additional toolbars (except for APM Graph toolbars) are Main (Parameters, Calculation and Results buttons), Contour, Forces, and Joints.

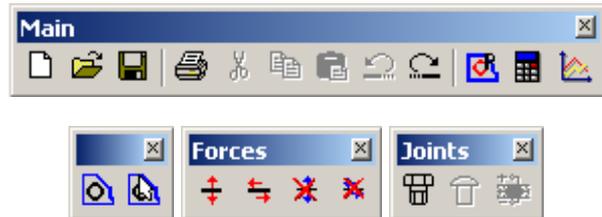


Fig. 2.2 Toolbars

Status bar

Status bar is used for presentation of useful information. This information includes cursor coordinates, current joint name, calculation type, etc.

Joint geometry. General principles

It is necessary to specify joint surface for threaded, riveted and butt-welded joint calculation. In **APM Joint** the joint surface is defined by the set of contours. A contour is the closed curve.

Joint geometry

The joint geometry can be set by three ways:

1. Imported to joint editor from *.dxf file.
2. Created in the joint editor.
3. Inserted from database in the form of parametrical model.

Let's consider each way in detail.

1. Geometry import from *.dxf file format is carried out by **File / Import...** command.
2. The description of joint geometry creation see in **APM Graph** user's guide.
3. The joint editor allows to load geometrical objects a contour of the joint presented in the form of graphic object from database. Graphic objects can be inserted from a database and, as a rule, represent parametrical models. These models need to be unblocked before calculation. Further we'll briefly consider the order of object insert from database. A parametric model from a separate file can be inserted as well.

Databases are managed by **APM Base** kernel (databases management system). The standard

APM Graph command **Draw / Block / Insert Object from Database...**  is used for access to databases.

It is possible to load parametric model from *.agp file. Use **Draw / Block / Insert Block** command .

It should be noted that any block or parametric model needs to be unblocked before contour selection. Use **Modify / Explode Block**  command for unblocking.

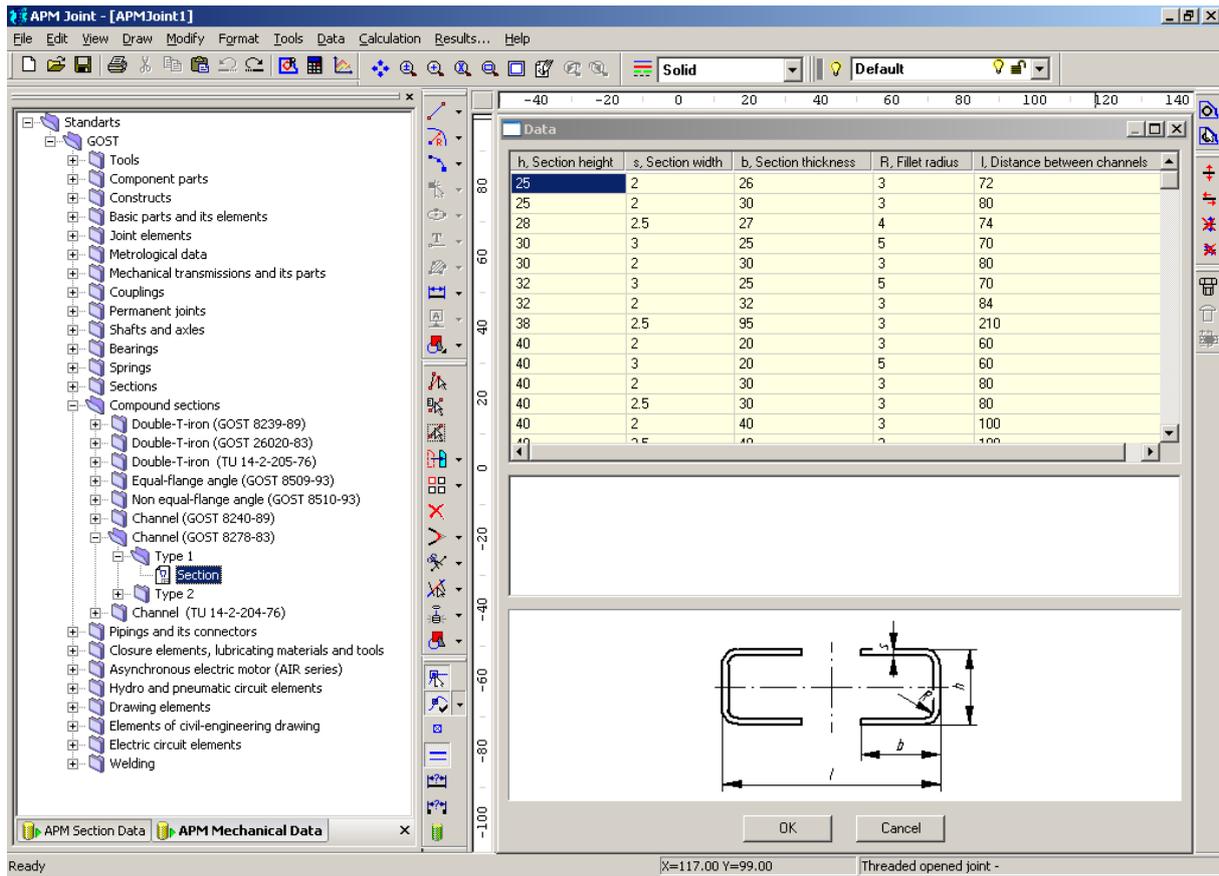


Fig. 2.3 Example of parametrical model insert from database

The next step is joint surface contours specifying by **Contour / Simple contour** and **Contour / User Defined Contour** commands.

You can save document at any time using **Save**  (File menu, File toolbar or Ctrl+S) or **File / Save As...** command.

Open button  (File menu, File toolbar or Ctrl+S) allows to open a file saved before *.wjt (APM Joint file).

Joint contours

Process of geometry creation consists of several stages. First, it is necessary to draw joint geometry using drawing tools such as line segments, arcs, etc. The next step is to define joint surface contours. The contour is the closed curve consisting of basic elements that can be drawn using Draw menu commands. Use **Contour / Simple contour** and **Contour / User Defined Contour** commands to define contours.

Simple Contour command activates the mode of automatic contour selection. To select a contour click the mouse on any contour element. First you should specify external contour and after that internal ones if any. The found contours are indicated by dark blue color. Corresponding contour can be found only if it is closed. Press **OK** button in contour dialog box after contours selection. The area inside the selected contours will be filled with a color. It means that joint surface is defined. To remove surface click mouse inside the surface area in delete mode .

 Remark. The contour can not be defined if it is created from segment connected not by means of control points but by the normal snapping for example. For definition of such contour break line (**Modify / Break at point** ) at cross point.



Fig. 2.4 Contour is not defined

User Defined Contour command activates the mode of closed contour selection manually. It is used when contours can not be defined automatically. For contour selection click mouse on contour elements one by one. To remove surface click mouse inside the surface area in delete mode .

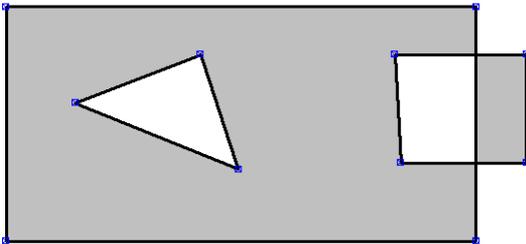


Fig. 2.5 Example of the contour definition by Simple Contour command

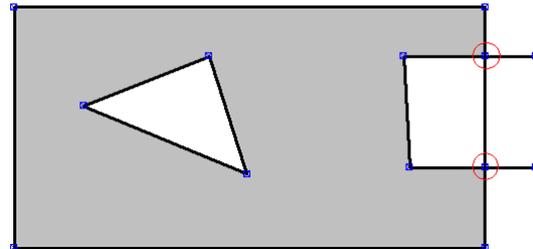


Fig. 2.6 Example of the contour definition by User Defined Contour command

Bolts, rivets and welding spots

For threaded, riveted joints and spot welding calculation it is necessary to place bolts, rivets and spots position accordingly. Use following commands of Data menu:  to place bolts (Ctrl + W),  to place rivet (Ctrl + W),  to place welding spots (Ctrl + W). It is possible to use object snaps in bolt/rivet/spot mode.

The **Modify / Edit**  command is used for objects moving (drag-&-drop).

The **Modify / Modify**  command is used for entering (editing) coordinates of bolts / rivets / welding spots with a keyboard (fig. 2.8).

The command **Modify / Erase**  is used for deleting selected objects.

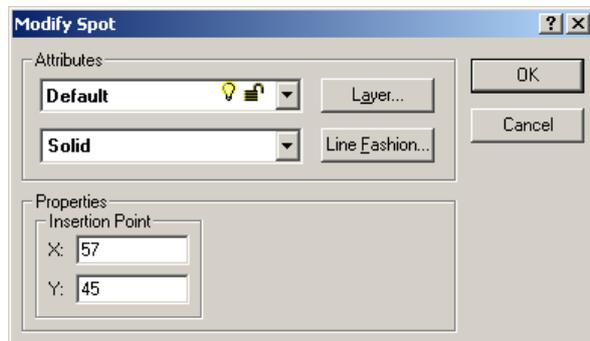


Fig. 2.8 Modify Spot dialog box

Loads

Loads of the certain types are supported in each joint type: shear forces and moments only or shear forces, normal forces and moments. Loads are entered by Data menu commands:  **Shear force** (Ctrl + A),  **Normal force** (Ctrl + O) and  **Moment** (Ctrl + M). To add load click left mouse button at load application point. Objective snaps are available in load modes. For details see corresponding commands in Command Reference chapter.

The command **Modify / Edit**  is used for objects moving (drag-&-drop).

The command **Modify / Modify**  is used for load modification (fig. 2.8).

The command **Modify / Erase**  is used for deleting selected objects.

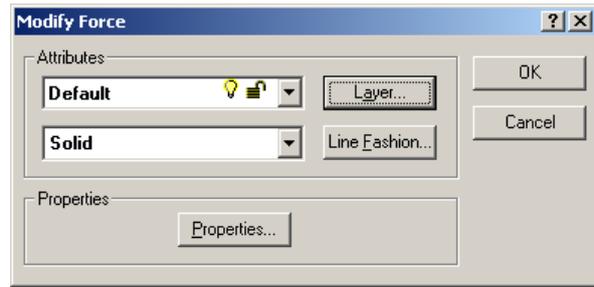


Fig. 2.8 Modify force dialog box

Chapter 3. Command Reference

All commands can be divided conditionally on commands for joint geometry creation (**APM Graph** commands) and commands for joint calculation (**APM Joint** commands). We shall consider **APM Joint** commands in detail. The detailed description of **APM Graph** commands is resulted in the corresponding documentation.

Further the full description of the menu commands and dialog window options of the **APM Joint** for not cylindrical joint types is resulted. The **APM Joint** main menu commands are shown below.

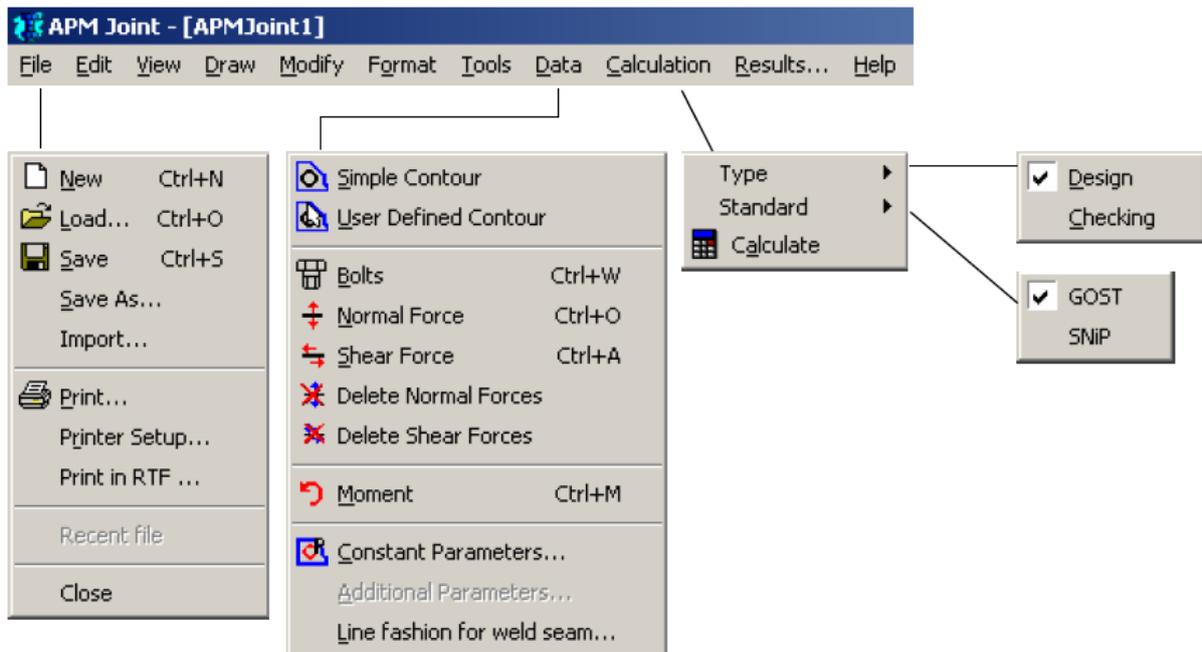


Fig. 3.1 APM Joint main menu commands for not cylindrical joint types

File menu

File menu commands are intended for new file creation and opening of saved files; for printing and importing of results; fast access to last opened files.

New

This command clears the working editor field and allows you to choose new joint type.

Shortcuts:  or Ctrl+N

Load

This command opens the *Open* dialog box shown below. You can choose **APM Joint** file saved earlier which you wish to open.

Shortcuts:  or Ctrl+O

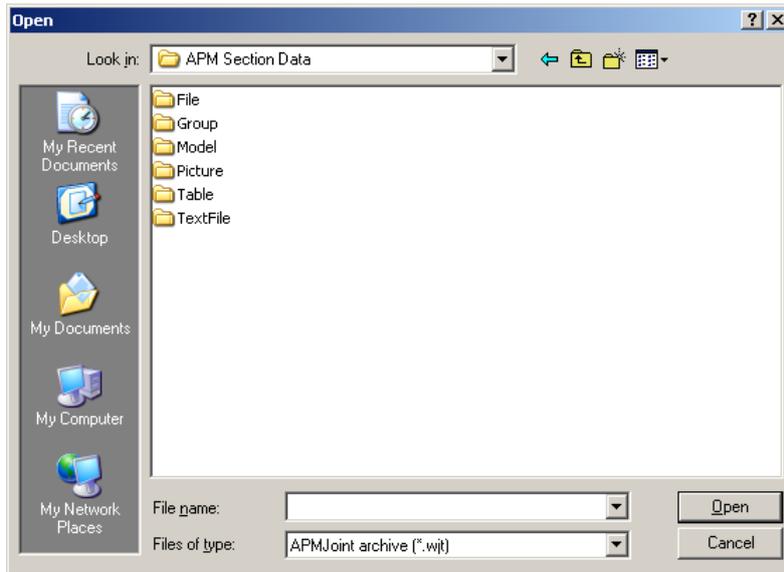


Fig. 3.2 Open dialog box

Save

This command opens the *Save As* dialog box shown below. You should enter file name where initial data and calculation results will be saved.

Shortcuts:  or Ctrl+S

Save As

This command allows you to save **APM Joint** file with other name.

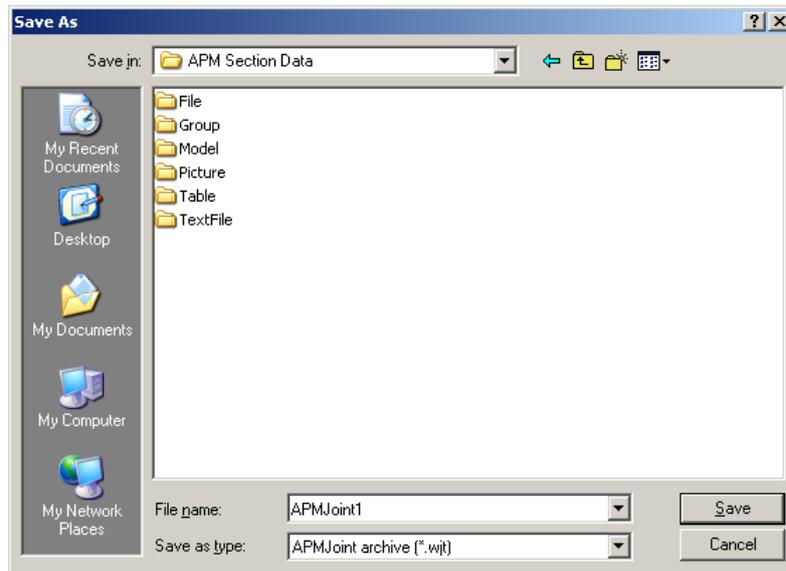


Fig. 3.3 Save as dialog box

Import...

This command opens the *Import* dialog box to import *.dxf file or *.agr file.

Print...

This command allows you to print joint geometry and calculation results. After this command was enabled, there will be standard dialog box on the screen, where you can set some print modes.

Shortcuts:  or Ctrl+P

Printer Setup...

This command enables *Print Setup* dialog box shown below. You can change print settings using this dialog box.

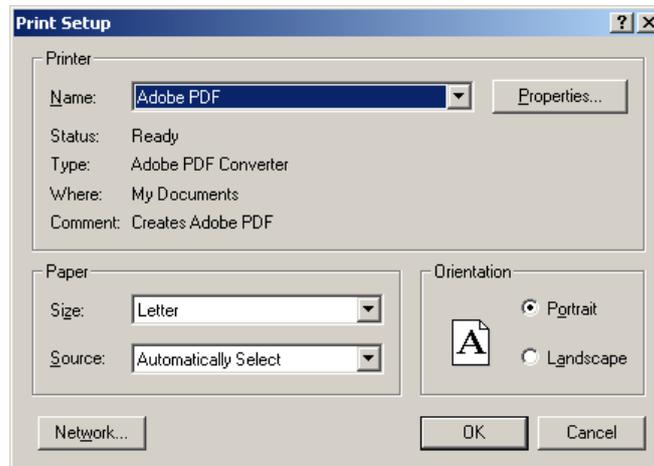


Fig. 3.4 Print setup dialog box

Print in RTF...

This command allows to generate and save text file of the report in *.rtf format. For this purpose it is necessary to specify folder, to enter file name and to press **Save** button in the appeared dialog box.

Recent File

This command opens most recently used files. Command name corresponds to file name. Menu can contain four of such commands.

Close

This command closes current file.

Data menu

This menu commands gives an opportunity of joint creation by means of simple contour or user defined contour, input of external loads and the constant parameters necessary for calculation.

Simple Contour

This command enables the mode of closed contour selection for joint surface definition. For contour selection move the cursor to one of the objects, entering in contour, and press the left mouse button. When the contour is found, it is allocated with color. To remove contour move the cursor to it and press the right mouse button.

Shortcut: 

User Defined Contour

This command enables the mode of closed contour selection consisting of several geometrical elements for joint surface definition. For contour selection move the cursor to one of the objects, entering in contour, and press the left mouse button. Then serially select all other elements making a contour. To remove contour move the cursor to it and press the right mouse button.

Shortcut: 

Bolts

This command allows you to place bolts for threaded joints. For bolt placing move the cursor to required point of joint surface and press the left mouse button. Object snaps are available. To set bolt coordinates from keyboard press **Space** key.

Use **Modify** /  **Modify** main menu command to edit bolt. In appeared dialog box you can change bolt coordinates and enter bolt diameter for checking calculation.

Use **Modify** /  **Erase** main menu command to delete bolt.

Shortcuts:  or Ctrl+W

Rivets

This command allows you to place rivets for riveted joints. This command is similar to **Data / Bolts** command.

Shortcuts:  or Ctrl+W

Weld spots

This command allows you to place spots for welded joints. This command is similar to **Data / Bolts** command.

Shortcuts:  or Ctrl+W

Normal Force

This command enables *Edit Normal Force* dialog box for designing calculation. For force placing move the cursor to required point and press the left mouse button.

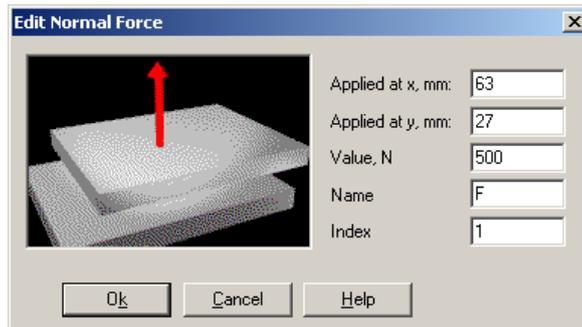


Fig. 3.5 Normal force dialog box

Edit Normal Force dialog box for designing calculation contains 5 text boxes for input of point coordinates, force value, force name and index. Enter demanded values and press button **OK**.

In checking calculation mode instead of this dialog box there is dialog box where it is necessary to enter the maximal and minimal force values instead of one force value.

Shortcuts:  or Ctrl+O

Shear Force

This command enables *Enter Force* dialog box for designing calculation. For force placing move the cursor to required point and press the left mouse button.

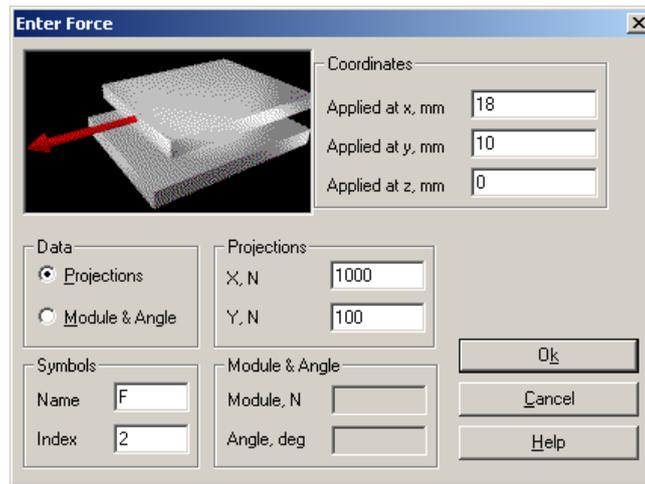


Fig. 3.6 Shear force dialog box

Enter Force dialog box for designing calculation contains 3 text boxes for input of point coordinates, 2 text boxes for entering of force projection values, 2 text boxes for entering of force modulus and angle and 2 text boxes for entering force name and index. Enter demanded values and press button **OK**.

In checking calculation mode instead of this dialog box there is dialog box shown below. This dialog box contains 3 text boxes for entering of force projection values, 4 text boxes for entering maximal and minimal force values and 2 text boxes for entering force name and index.

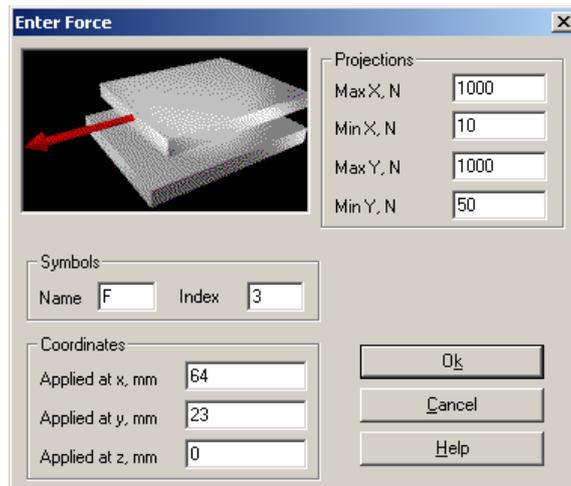


Fig. 3.7 Shear force dialog box

Shortcuts:  or Ctrl+A

Delete Normal Forces

This command allows you to delete all normal forces.

Shortcut: 

Delete Shear Forces

This command allows you to delete all shear forces.

Shortcut: 

Moment

This command enables *Moment* dialog box (fig. 3.8a). For moment placing move the cursor to required point and press the left mouse button.

Moment dialog box for designing calculation contains 3 text boxes for input of point coordinates, 3 text boxes for entering of moment values around X, Y and Z axis and 2 text boxes for entering moment name and index. Enter demanded values and press button **OK**.

In checking calculation mode this command invokes *Moment* dialog box (fig. 3.8b). The minimal and maximal values of moment are set for checking calculation unlike dialog of designing calculation.

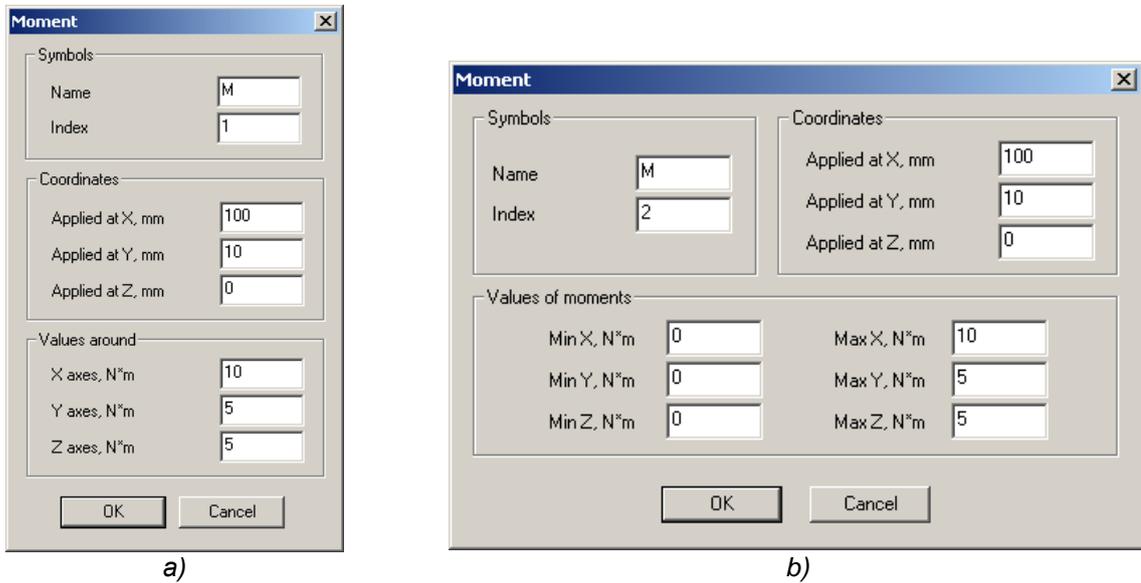


Fig. 3.8 Moment dialog box

Shortcuts:  or Ctrl+M

Constant Parameters...

This command enables *General Parameters* dialog box. This dialog box contains text boxes for input of parameter values necessary for calculation according to GOST (fig. 3.9a), such as *Safety Factor for Unopening*, *Safety Factor for Shearing*, *Main Load Factor*, *Safety Factor for Yield*, *Yield Point*, *Friction Coefficient*, *Breaking Strength*. Another dialog box shown on fig. 3.9b contains parameters according to SNIP.

Press **Data Base...** button to load material properties from material database.

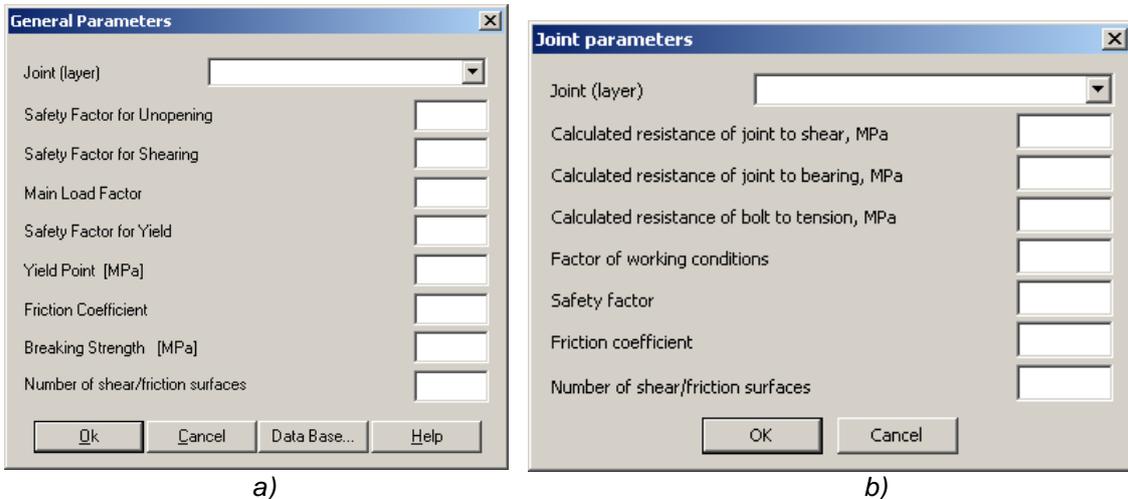


Fig. 3.9 General parameters dialog box

Shortcut: 

Additional Parameters...

This command enables dialog box shown below. This dialog box contains text boxes for input of parameters used in checking calculation. *Diameter* is bolt diameter for threaded joints, rivet diameter for riveted joints, spot diameter for spot welding. Weld leg is specified for other welded joints. There is *Effective Stress Concentration Ratio* parameter for all types of welded joints.

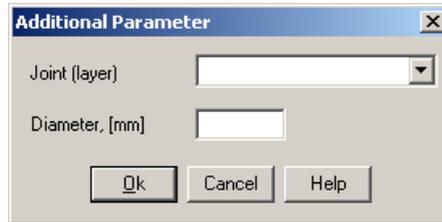


Fig. 3.10 Additional parameters dialog box

Line fashion for weld seam...

This command allows to select weld seam line fashion. All the created objects formatted by this line fashion type will be calculated as a weld seam (for single- or double-sided weld seam).



Fig. 3.11 Line fashion for weld seam dialog box

Calculation menu

Type

This command allows you to set calculation type (**Design** or **Checking**)

Standard

This command allows to select standard (**GOST** or **SNIP**)

Calculate

This command allows you to calculate joint depending on calculation type.

Shortcut: 

Results...

This command invokes *Results* window for current joint type and calculation type.

Contents

This command shows help contents.

About...

This command invokes *About APM Joint* dialog box that contains information about the program.

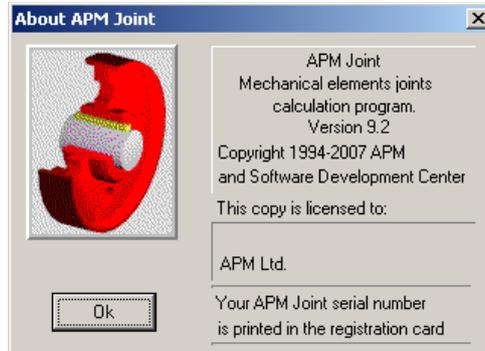


Fig. 3.13 About APM Joint dialog box

Chapter 4. Joint design step by step

Calculation of joints, described in this chapter, has many common points. The general scheme of calculation includes the following steps:

- 1) Selection of calculation type: design or checking
- 2) Selection of standard type: GOST or SNIP
- 3) Geometry definition
- 4) Entering forces, acting on the joint
- 5) Initial data entering
- 6) Calculation
- 7) Looking through results

Now we can describe the calculation steps.

- 1) **Calculation type: design or checking (Calculation / Type command).**

Design calculation is intended to get general parameters of joint using formulae that are based on the most important criteria, such as strength, wear resistance, etc. Design calculations have the preliminary, estimating nature.

Checking calculation allows getting more specific results about joint under consideration. Checking calculation is performed when configuration and dimensions of joint either are known as result of design calculation, or are accepted basing on the construction requirements.

- 2) **Standard type: GOST or SNIP (Calculation / Standard command).**

The selection of calculation methods is caused by application field of joint. Calculation of joints in mechanical engineering is carried out in accordance with GOST, and calculation of building joints in conformity with SNIP.

- 3) **Geometry definition.** To specify joint geometry the APM Joint editor is used. Detailed description of this system is given in chapter 2. It contains sufficient number of primitive types, allowing drawing joints of arbitrary shape with arbitrary arrangement of joint elements.

!!! Remark. *Joint geometry and loads applied to it should be in one layer.*

- 4) **Load application.** To enter the loads, acting on the joint, the same graphical editor is used. Both normal and tangent forces can be entered; tangent forces can be applied in the joint plane or at some distance from it. When design calculation is performed the constant loads only can be entered, when checking - both constant and variable ones.

- 5) **Initial data entering.** To make calculation user should enter material properties - ultimate strength, yield strength, friction coefficient, as well as safety ratios. See **Constant Parameters** command in *Command Reference* chapter.

- 6) **Calculation.** To execute calculation select **Calculation / Calculate** main menu command.

- 7) **Looking through the results.** To look through calculation results use **Results...** command in the main menu.

Specifics of joint models transferred from APM Structure3D

Each rod with its nodal loads transferred to a separate layer. Layer name consists of rod number and cross-section name, for example, Rod 18 L40x4 GOST 8509-93. Every layer represents as a separate joint. Therefore, to edit joint geometry, select joint layer first (make layer active), and then set contour of bolted joint or weld seam.

Below we describe the features that are specific for each type of joint.

Threaded joints

Geometry definition. To specify geometry of threaded joint user should define the shape of base surface and place the bolts on it.

The shape of base surface is defined as a set of its external and internal boundaries. Multiply connected surfaces that consist of a number of isolated parts are permissible. Surface boundaries consist of contours. Contour is the closed line; it can be *simple* or *compound*. The simple contour consists of one primitive, for example rectangle or circle. Compound contour is formed by a set of

primitives (line segments, arcs) and by fragments of primitives that are cut off by another primitives. In fig. 2.2 the examples of base surfaces are shown together with contours they are formed by.

After the base surface is specified you should place bolts on it. To place bolts use **Data / Bolts** command.

Load entering. When threaded joint is calculated, the loads can be applied to any point (not only to that belonging to joint surface). For threaded closed joints only loads applied in joint plane are allowed, whereas for opened joint both loads applied in joint plane and the normal loads are permissible. You can enter the loads using **Data / Normal Force**, **Data / Shear Force** and **Data / Moment** menu commands. For details see *Command Reference* chapter.

Initial data entering. Initial data that are used in the threaded joint calculation are described in Chapter 1 "Problems, initial data and results", menu commands and dialog boxes used for this purpose are listed in Chapter 3 "Command Reference".

Design calculation. At this step the geometry parameters (surface area, moments, center of mass) are calculated, as well as loads acting on bolts.

Checking calculation. The checking calculation is performed after design calculation and with the same geometry that was used for the former one. User should enter variable external loads using the same **Data / Normal Force**, **Shear Force** and **Data / Moment** menu commands as for the design calculation. Besides that you can also change the bolt diameter with **Data / Additional Parameters...** command.

Riveted joints

Geometry definition. Rivet joint geometry is specified just in the same way as that for threaded closed joints. The only difference is that rivets are placed using **Data / Rivets** command.

Load entering. For riveted joints only shear forces and moments, applied in the joint plane are allowable, since these joints are calculated for rivet cutting.

Initial data entering. See Chapter 1 "Problems, initial data and results" for used parameters and Chapter 3 "Command Reference" for respective menu commands and dialog boxes.

Design and checking calculation for riveted joints are similar to closed threaded joints calculations.

Tee and lap welded joints

Geometry definition. These joints consist of a number of seams that can have an arbitrary shape and can be located in the arbitrary manner. To draw tee and lap welded joints use APM Joint editor, described in Chapter 2.

Load entering. User can enter normal and shear forces, acting to joint.

Checking calculation. When performing checking calculation user can enter variable loads instead of constant ones and change values of weld seam leg and effective stress concentration ratio.

Spot welded joint

Geometry definition. To enter geometry of these joints use **Data / Spots** that allows to arrange the spots in the joint plane.

Load entering. Only shear forces and moments are allowable for these joints only.

Checking calculation. Performing checking calculation user can enter variable loads together with constant ones and change values of spot diameter and effective stress concentration ratio.

Butt welded joints

Geometry definition. Geometry of butt welded joint is determined in the same manner as that of threaded joints (see above).

Load entering. Both normal and shear forces and moments are allowable for joints of this type.

Checking calculation. When performing checking calculation user can enter variable loads and effective stress concentration ratio.

Chapter 5. Subsystem for cylindrical machine element joint calculation

This chapter gives full description of menu commands and dialog boxes options in subsystem for cylindrical machine element joint calculation **APM Joint**.

Command reference

The main menu for these joints is shown below.

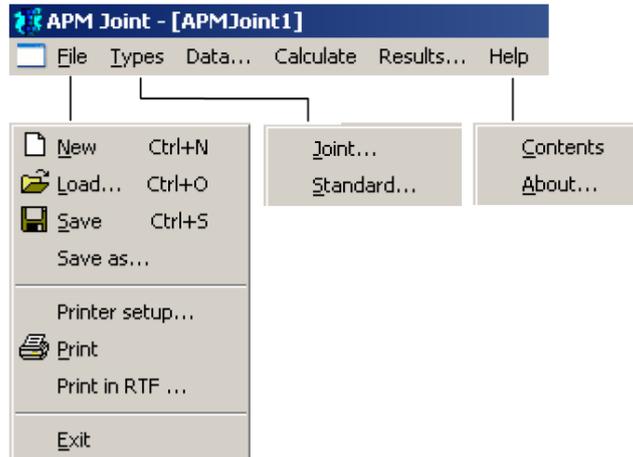


Fig. 5.1 APM Joint main menu commands for cylindrical joint types

New

This command clears the working editor field and allows you to choose new joint type.

Shortcuts:  or Ctrl+N

Load

This command opens the *Open* dialog box. You can choose **APM Joint** file saved earlier which you wish to open.

Shortcuts:  or Ctrl+O

Save

This command opens the *Save As* dialog box. You should enter file name where initial data and calculation results will be saved.

Shortcuts:  or Ctrl+S

Save As

This command allows you to save **APM Joint** file with other name.

Print...

This command allows you to print joint geometry and calculation results. After this command was enabled, there will be standard dialog box on the screen, where you can set some print modes.

Shortcuts:  or Ctrl+P

Printer Setup...

This command enables *Print Setup* dialog box. You can change print settings using this dialog box.

Print in RTF...

This command allows to generate and save text file of the report in *.rtf format. For this purpose it is necessary to specify folder, to enter file name and to press **Save** button in the appeared dialog box.

Recent File

This command opens most recently used files. Command name corresponds to file name. Menu can contain four of such commands.

Exit

This command closes current file.

Joint...

This command enables dialog box where you can select joint type.

Standard...

This command enables dialog box where you can set standard which will be used at data choice from database.

Data...

This command invokes dialog box for initial data entering.

Calculate

This command allows you to calculate joint.

Shortcut: 

Results...

This command allows you to look through calculation results.

Shortcut: 

Contents

This command shows help contents.

About...

This command invokes *About APM Joint* dialog box that contains information about the program.

Calculation order

Joint calculation includes following stages:

- 1) Joint type selection
- 2) Entering of initial data necessary for calculation
- 3) Calculation
- 4) Viewing of calculation results
- 5) Saving and printing of calculation results

Let's consider each stage of calculation in detail.

1) Joint type selection. The command **Types / Joint...** is used for joint type selection. Select joint type and press button **OK** in the appeared dialog box shown below.

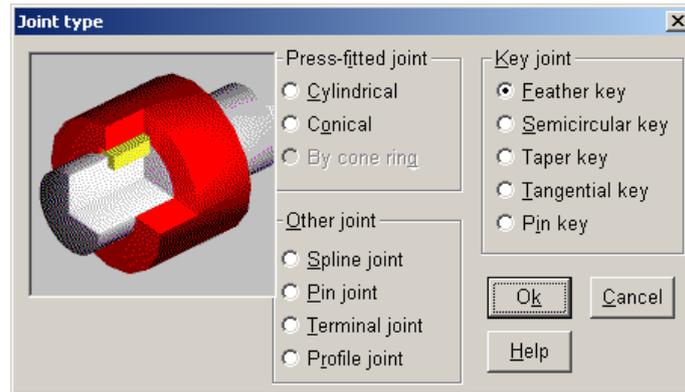


Fig. 5.2 Joint type dialog box

2) Entering of initial data necessary for calculation. The command **Data...** is used for data input necessary for calculation of concrete joint type and invokes *Initial Data* dialog box shown below. The initial data presented in this dialog box are obligatory for input. Additional data entering is carried out by **More...** button. User can enter *allowable stresses* if it is necessary. By default the *allowable bearing stress* value in view of safety factor is defined by yield stress and depends on load type and material properties.

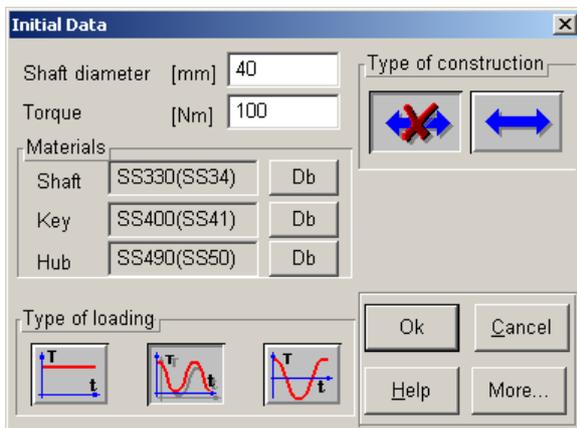


Fig. 5.3 Initial Data dialog box

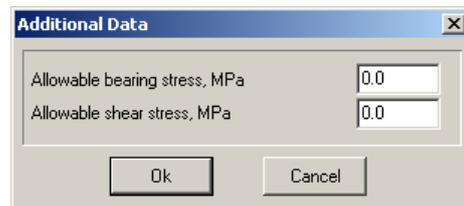


Fig. 5.4 Additional Data dialog box

Db buttons are used for material selection from database.

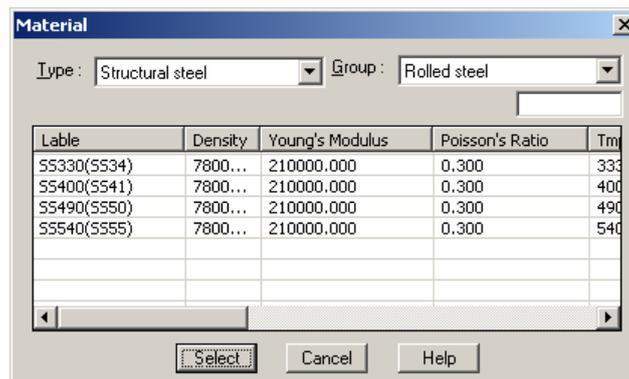
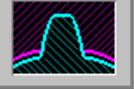
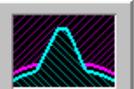


Fig. 5.5 Material dialog box

Pictographic buttons are present in some windows. We shall consider each pictographic button.

Table 5.1 – Pictographic buttons

Parameter type	Button	Description
Type of loading		Constant load
		Pulsatory load
		Cyclic load
Type of construction		Hub can move along shaft
		Hub can not move along shaft
Spline type		Involute spline
		Square-sided spline
		Triangle spline

3) Calculation. Press  **Calculate** button for joint calculation.

4) Viewing of calculation results. To look through calculation results use the **Results...** command

 that displays dialog box depending on joint type.

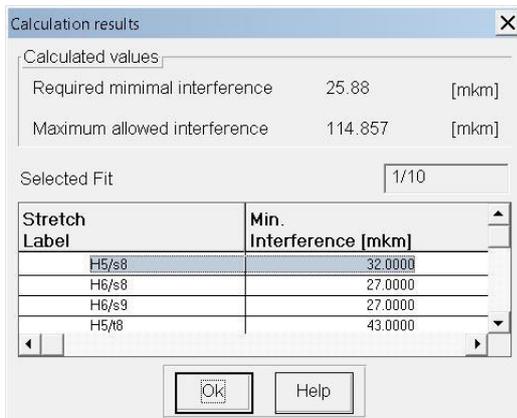


Fig. 5.6 Press-fitted joint calculation results

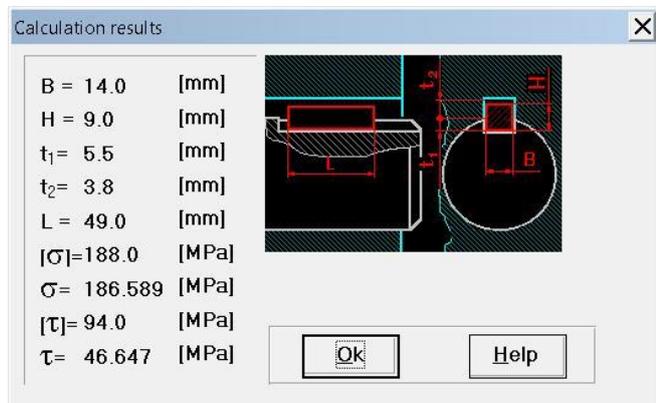


Fig. 5.7 Feather key calculation results

5) Saving and printing of calculation results. For saving of initial data and calculation results, press the  **Save** button. You can set some print modes and print initial data and calculation results by command **File / Print** . **File / Print in RTF...** command allows to generate and save text file of the report in *.rtf format.