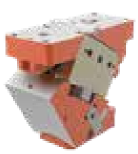
OVERVIEW SPECIFICATIONS

	Sliding pair	Features	Guaranteed number of strokes / lifetime	Working angle	Angle Increments (step size)	Width [mm]
2016.11. DIE MOUNT CAM STANDARD				Request catalogue 2.2911.!		
	Sliding planes: Cast / Cast with solid lubricant	unpopulated with compression spring	300,000	0°	--	52 – 400
2016.12. HORIZONTAL BAK STANDARD				Request catalogue 2.2911.!		
	Sliding planes: Hardened steel / bronze with solid lubricant	Fully equipped, shouldered guide bars, gas springs correspond to the NAAMS standard	1,000,000	0°	--	65 – 150
2016.14. HORIZONTAL				Request catalogue 2.2911.!		
	Sliding planes: Hardened steel / bronze with solid lubricant	Partly populated with compression spring	600,000	0°	--	52 – 400
2016.207. AERIAL CAM ECO LINE						
	Sliding planes: Hardened steel / bronze with solid lubricant	Fully equipped Guide bars Gas spring	1,000,000	0° – 60°	5°	70 – 400
2016.208. AERIAL CAM ECO LINE						
	Sliding planes: Hardened steel / bronze with solid lubricant	Fully equipped, Guide bars, gas spring	1,000,000	0° – 60°	10°	500 – 1000
2016.21. AERIAL CAM STANDARD				Request catalogue 2.2911.!		
	Sliding planes: Cast / Cast with solid lubricant	unpopulated with screw compression spring	300,000	0° – 70°	10°	65 – 200

OVERVIEW SPECIFICATIONS

	Sliding pair	Features	Guaranteed number of strokes / lifetime	Working angle	Angle Increments (step size)	Width [mm]
2016.22. AERIAL CAM				**Request catalogue 2.2911.!**		
	Sliding planes: Hardened steel / bronze with solid lubricant	Fully equipped, shouldered Guide bars, prismatic guide, Gas spring	1,000,000	0° – 70°	10°	65 – 200
2016.23. AERIAL CAM KBV1				**Request catalogue 2.2911.!**		
	Sliding planes: Hardened steel / bronze with solid lubricant	Fully equipped, shouldered Guide bars, gas springs correspond to the NAAMS standard	1,000,000	0° – 60°	5°	50 – 300
2016.24. AERIAL CAM FCC						
	Sliding planes: Hardened steel / bronze with solid lubricant	Fully equipped, shouldered Guide bars; sliding guide as double prismatic guide; gas spring, fulfils the BAK contract specification	1,000,000	0° – 75°	5°	60 – 600
2016.25. AERIAL CAM FCC						
	Sliding planes: Hardened steel / bronze with solid lubricant	Fully equipped, shouldered Guide bars, gas spring, fulfils the BAK contract specification	1,000,000	0° – 75°	5°	700 – 1050
2016.34. SLOPED				**Request catalogue 2.2911.!**		
	Sliding planes: Hardened steel / bronze with solid lubricant	Partly populated with compression spring	600,000	10° – 20°	10°	65 – 150

ENGINEERING

The FIBRO cam unit program offers matching system solutions for the widest range of applications. From the use in progressive punching tools with the smallest dimensions up to the demanding use in large tools. From the use in tools with small piece numbers up to premium applications in the manufacture of bodywork parts with the highest requirements in terms of precision, lifetime and process force transmission, our cam unit program offers the matching solution to your application. The fault-free operation is guaranteed by FIBRO over the guaranteed, nominal lifetime. The design of the cam units, in the course of the tool construction, is indispensable in this regard. Operating conditions of the tool, as well as the expected environmental influences, must be taken into account to the best extent possible. Using a precise and conscientious design, it is possible to achieve a lifetime which extends far beyond the guaranteed stroke rate.

The desired lifetime can only be achieved by using the cam units as intended. An overloading of the cam units will reduce the number of strokes of the cam unit and can, in the extreme case, lead to the immediate failure of the cam unit during the initial strokes.
The operational reliability of FIBRO cam units is demonstrated by the guaranteed number of strokes. The size of the working force, the position of the center of the force on the working surface and the sequence of the introduction of the force, all have an effect on the system. All performance specifications were calculated using factors known to us at the time of printing. Changed operation conditions can influence the lifetime of the cam unit and must be taken into account separately in consultation with the operator.

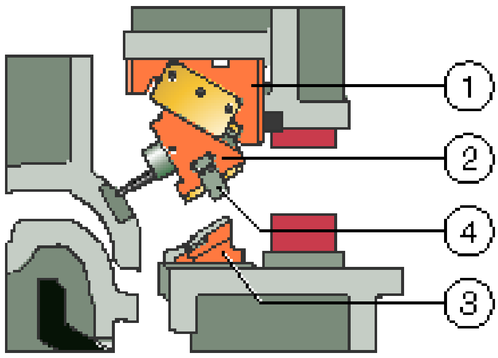
FIBRO supports you competently throughout the entire process chain: Starting with the selection of a suitable cam unit for your application, to the correct design, up to the delivery of the cam unit to the assembly, FIBRO is by your side when you have questions. After the completion of the engineering and assembly phase, FIBRO's after-sales support also provides you with professional support for your needs. Take advantage of our experience as a standard system supplier for toolmaking and customise your tools with our products to your specific applications in the most optimal way.

Content overview chapter “ENGINEERING”

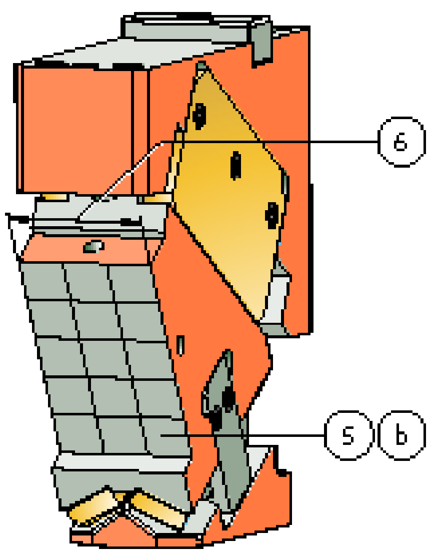
ENGINEERING
DEFINITION OF TERMS

Installed state,
Depicted 100 mm in front of bottom dead center

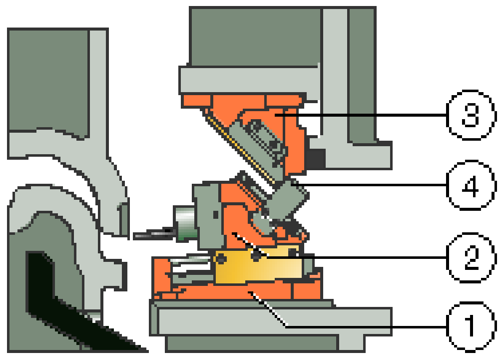
Aerial cam unit (I)



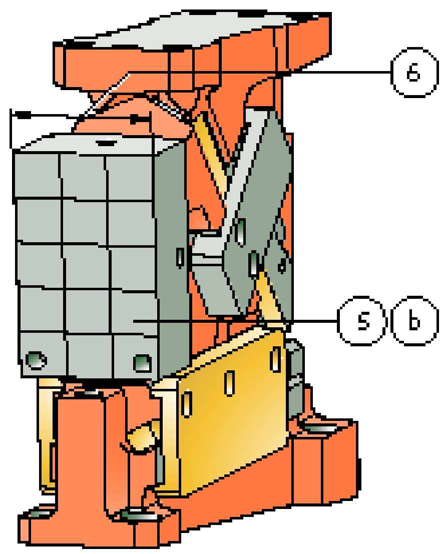
Cam unit mounted in the upper die:
Lifts with upper die during the course of the press cycle.



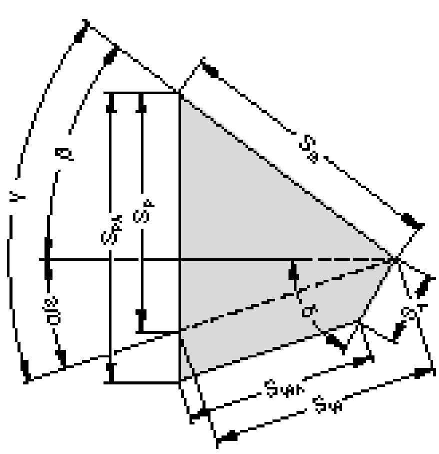
Die mounted cam unit (II)

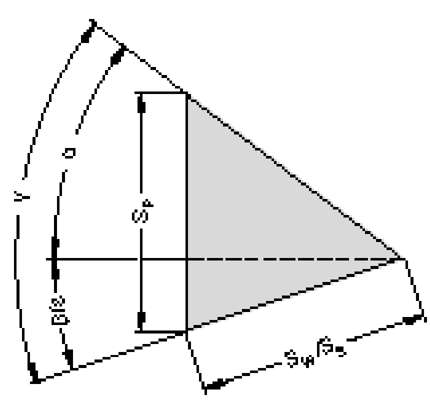


Cam unit mounted in the lower die:
Remains seating on the lower die during the course of the press cycle.



Cam diagram (A)





Subject to alterations

ENGINEERING
DEFINITION OF TERMS

(I)	**Aerial cam unit**	Assembly cam base / cam slider is mounted in the upper die, the driver in the lower die. Aerial cams are preferably utilised to increase press cycle times.
(II)	**Die mounted cam unit**	Assembly cam base / cam slider is mounted in the lower die, the driver in the upper die. Die mounted cam units improve the tool dynamics, since the moved mass is reduced in the upper die.

(1)	**Cam base**	Assembly for receiving the traveling slide body.
(2)	**Cam slider**	Assembly with the working surface for accommodating the tool-specific components. The cam slider assembly is mounted in the cam base so that it travels linearly.
(3)	**Cam driver**	Component or assembly which drives the slider body in the course of the press movement.
(4)	**Positive return**	Constructional device on the cam unit, which retracts the slide body mechanically during the upwards stroke of the press into the initial position.
no figure	**Pre-acceleration**	Constructional device on the cam unit, which influences the acceleration and braking behaviour of the cam slider in the press stroke. Version as plate or roll pre-acceleration possible.
(5)	**Working surface**	Surface on the cam slider for accommodating the tool-specific components.
(6)	**Working width**	Width of working surface

no figure	**Maximum permissible working force**	Maximum permissible force acting perpendicular to the working surface, with which the cam unit achieves the nominally guaranteed lifetime.
(b)	**Force diagram**	Specifies the maximum permissible working force when the centre of the force is located in different sectors on the working surface.
no figure	**Stripper force**	The force required by the parameters of the working process, which is necessary to return the tools to the initial position (tool / process-condition) after reaching the presses bottom dead center.
no figure	**Retraction force**	Constructionally related force of the cam unit, which returns it to the starting position after reaching the presses bottom dead center.
no figure	**Return force**	Force which is necessary in order to return the cam slider in the cam base back to the initial position without the action of a process-related stripper force.
no figure	**Spring force**	Constructionally related nominal force of the spring component used in the cam unit

(A)	**Cam diagram**	Represents the angle and distance ratios of the cam unit.
(ε)	**Cam angle**	Operating direction of the cam unit - angle of the cam unit working direction measured to the horizontal.
(α)	**Driver angle**	Angle of the driver gliding surface measured to the horizontal.
(β)	**Base angle**	Angle of the cam base gliding surface measured to the horizontal.
(γ)	**Included angle**	Angle of the sliding surfaces on the cam slider between driver and base.
(δ)	**Pre-acceleration angle**	Angle of the pre-acceleration gliding surface measured to the horizontal.
(S_W)	**Cam stroke**	Usable stroke in the working direction of the cam unit (representation aerial cam unit with and without pre-acceleration).
(S_S)	**Spring stroke**	Stroke of the spring in the cam unit.
(S_P)	**Press stroke**	Distance in the press direction required to close the cam unit completely.
(S_A)	**Pre-acceleration stroke**	Stroke which the cam unit travels when a pre-acceleration mechanism is used in the direction of the latter.

ENGINEERING
LEGEND / PARAMETER DIRECTORY

W_T	Cutting work	[Nm]
B	Width	[mm]
C_A	Centre of the force of the stripper	
C_B	Centre of working force	
C_F	Centre of force	
C_n	Centre of mass n	
D	Diagonal dimension	[mm]
F	Force	[kN]
F_A	Stripper force	[kN]
F_B	Operating force	[kN]
F_{hn}	Horizontal force n	[kN]
F_P	Force for punching	[kN]
F_{pp}	Return force	[kN]
F_R	Retraction force	[kN]
F_S	Spring force	[kN]
F_T	Cutting force	[kN]
F_{vn}	Vertical force n	[kN]
F_W	Working force	[kN]
H	Installation height	[mm]
H_1	Distance reference point / support top	[mm]
Hn	Height shoulder n	[mm]
H_W	Height of the working surface	[mm]
K	Cutting contour	
l	Cutting length	[mm]
l_n	Length contour element n	[mm]
L	Length	[mm]
L_1	Distance reference point / stop top	[mm]
L_2	Clamping surface top	[mm]
L_3	Distance reference point / stop bottom	[mm]
L_4	Clamping surface bottom	[mm]
L_5	Distance reference point to the top edge Working surface	[mm]
n	Counter	
P_n	Punch counter n	
R_m	Tensile strength	[N/mm²]
s	Sheet metal thickness	[mm]
S	Stroke	[mm]
S_A	Pre-acceleration stroke	[mm]
S_P	Press stroke	[mm]
S_{PA}	Press stroke with pre-acceleration	[mm]
S_S	Spring stroke	[mm]
S_W	Cam unit stroke	[mm]
S_{WA}	Cam unit stroke with pre-acceleration	[mm]
t	Time	[s]
u	Protrusion	[mm]
u_s	Protrusion to side	[mm]
u_f	Protrusion to front	[mm]
B_W	Working width	[mm]
x_n	Distance n x-direction	[mm]
y_n	Distance n y-direction	[mm]
α	Driver angle	[°]
β	Cam base angle	[°]
γ	Included angle	[°]
δ	Pre-acceleration angle	[°]
ε	Cam unit angle	[°]
τ_T	Shear strength	[N/mm²]
x_{CA}	Centre of mass of the stripper in x-direction	[mm]
y_{CA}	Centre of mass of the stripper in y-direction	[mm]
x_{Ctotal}	Centre of mass in x-direction, total	[mm]
y_{Ctotal}	Centre of mass in y-direction, total	[mm]

ENGINEERING
DESIGN TOOL CONNECTION

The size of the maximum force transferable by the cam unit is significantly influenced by the type of installation chosen. A technically correct selection of the installation type must be considered analogue to the cam unit design.

The working force can be transmitted via the shoulder of the cam base on FIBRO cam units, alternatively via concealed fitting wedges on the cam base support. The shouldered installation allows maximum load values to be transferred, while a compact mounting space can be realized by installing via the concealed seating wedges. The reduced load values must be observed when installing via the feather keys.

The manufacture of the cam unit interface in the tool can be optimised by means of simple constructional solutions and cost-effectively, without loss of performance.

Force transmission via shoulder

The maximum power values of the cam unit are achieved by the shouldering of the cam base in the nominal shoulder height (see catalogue specifications). It is not necessary to shoulder the die over the entire height of the cam base.

In the following, three possible versions of the shouldering of the cam base in the die are shown, the designs 2 + 3 thereof are preferred since production is optimised.

1. Shouldering over entire cam base height

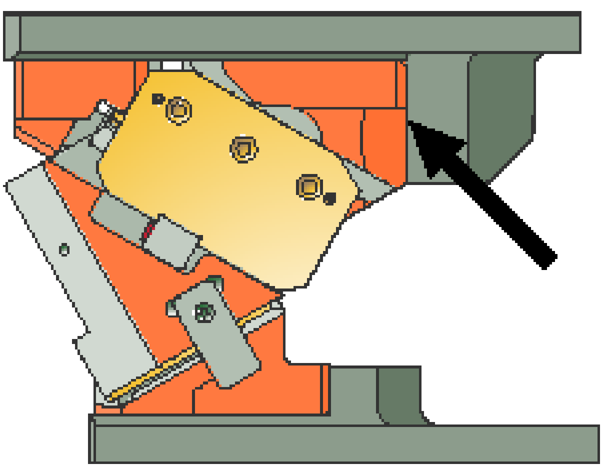


Figure 1: Cam base completely shouldered

ENGINEERING
DESIGN TOOL CONNECTION

2. Shouldering via cast shoulder in the upper area of the cam base, lower area exposed

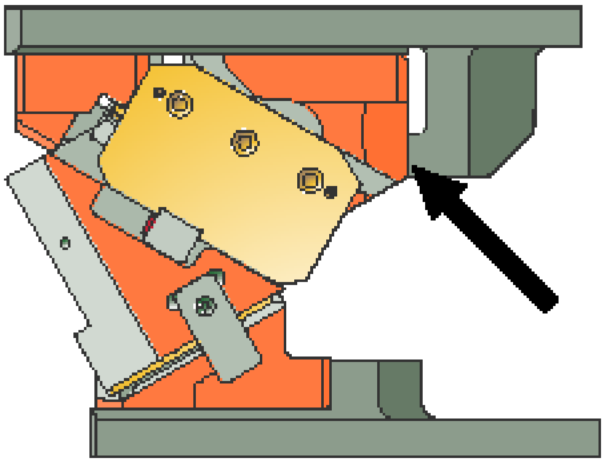


Figure 2: Cam base shouldered at top

3. Shouldering via inserted feather key between cam base and die casting in the upper area of the cam base, lower area exposed

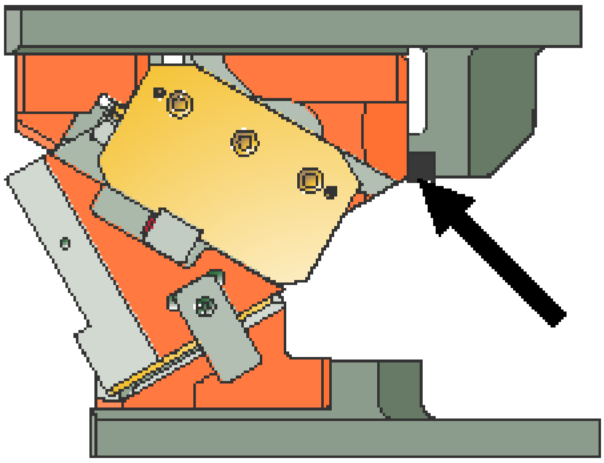


Figure 3: Cam base shouldered at top with key

ENGINEERING
DESIGN TOOL CONNECTION

Force transmission via feather key

In the case of lower requirements on the transmission of force, the cam unit can be installed in the tool by means of bracing via the key so that it is optimised to the installation space. For the mechanical machining of the feather key groove, in this case a distance from the groove geometry to the possible interference geometries in the die cast of at least 140 mm must be observed in order to avoid a collision of the milling spindle.

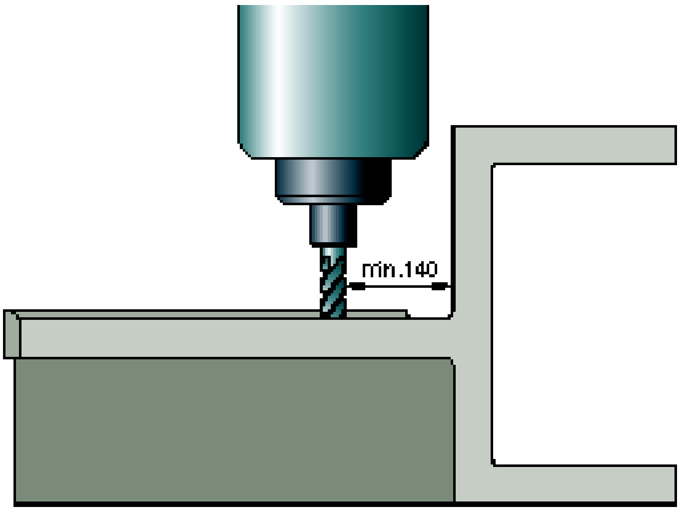


Figure 4: Milling spindle clearance

FIBRO cam units must be fitted with head cap screws having strength class 8.8 or higher.

ENGINEERING
CAM UNIT DESIGN

The operating reliability is demonstrated independently of the operating mode as follows:

1. Evaluation of the calculated operating force
2. Evaluation of the arithmetical centre of force and formation of the substitute force
3. Comparison of the substitute force with permissible force

The operating force is generated by the tools mounted on the cam during the engagement in the sheet metal. When determining the operating forces, the following operating modes are distinguished:

a) Cutting
b) Punching
c) Forming
d) Operations with additional stripper

a) Cutting

During cutting, the operating force is created by overcoming the shear strength of the machined sheet metal part.

The force is calculated using the formula:

$$F_S = l \times s \times \tau_T \qquad [1]$$

Cutting length [l] and sheet thickness [s] are taken from the method plan, the shear strength [τ] from material tables. If there are no values for the shear strength, this can be approximately determined from the tensile strength. For ductile materials, this amounts to between 60 and 90% of the tensile strength.

In general, the maximum value of the possible characteristic range of the sheet material must be used as a basis for the calculation because the steel grades are produced and delivered within the specified range. Thus, the characteristic values of the processed sheets can assume the highest permissible characteristic values and thus also the highest possible loads on the tool components can be applied.

For evaluating the cam unit stability, the centre of force applied by the cutting is determined and compared with the force diagram of the desired cam unit. The centre of force of the cutting is determined by means of the centre of mass of the cutting line. For this purpose, complex, free-shaped sections can be dissected into a sufficiently precisely segmented substitute contour with known segment focal points (see Fig. 5)

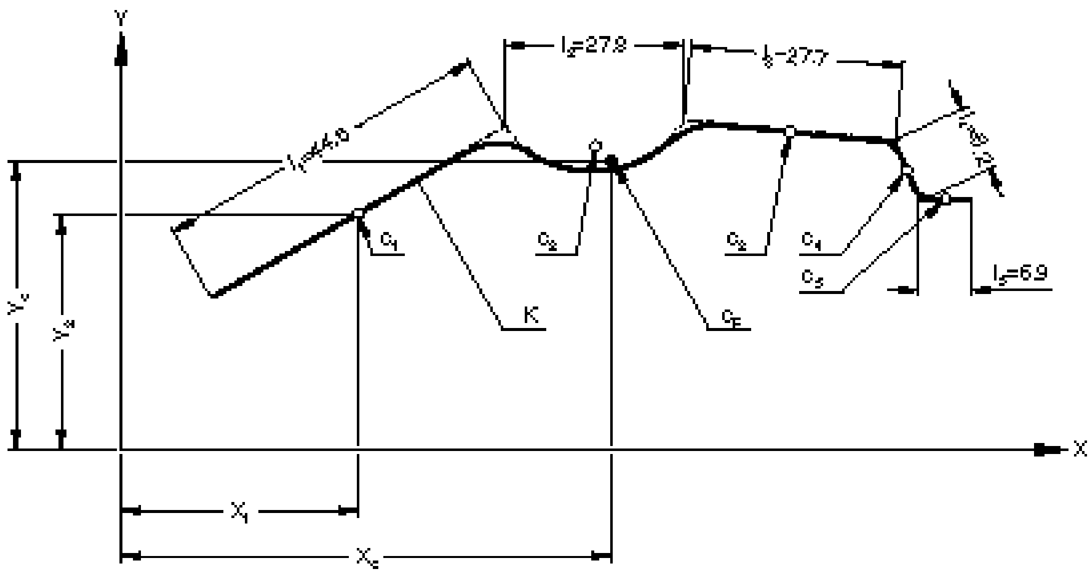


Figure 5: Cutting contour original and approximated

The total centre of force is determined from the individual segments of the line:

x value:

$$x_C = (x_1 \times l_1 + x_2 \times l_2 + x_n \times l_n) / (l_1 + l_2 + l_3) \quad [2]$$

y value:

$$y_C = (y_1 \times l_1 + y_2 \times l_2 + y_n \times l_n) / (l_1 + l_2 + l_3) \quad [3]$$

The following boundary conditions apply to the calculation model:

In this determination of the centre of force, a uniform trim steel engagement is assumed. A non-uniform trim steel engagement determines both the change in the cutting force F_T as well as the centre of the force C_F over the cutting line t_T.

Force-reducing measures such as, for example, the targeted manipulation of the cutting line are not taken into account in this consideration. The modification of the strength values by a cold work hardening of the material in preliminary forming operations is likewise not taken into account in this consideration. It applies in particular to modern, high-strength materials for vehicle structural components (e.g. in dual phase steels) and depends on the material as well as on the degree of metal forming. Cold work hardening effects must be taken into account in the individual case in the design of the cam unit. If a stripper is used on the cam unit, the loading by the stripper must be taken into account accordingly (see section d).

ENGINEERING
CAM UNIT DESIGN

b) Punching

Punching is a special form of cutting. The determination of the operating force thus follows a similar scheme, although some important particulars have to be considered.

The determination of the force is performed analogous to the calculation of the force during cutting. In the case of punching operations, several punches are often arranged on a cam unit. In this case, the force introduced by each punch must be determined as well as the sum of all individual forces.

$$F_{Pn} = l_n \times s \times \tau_T \quad [4]$$

$$F_{Ptotal} = F_{P1} + F_{P2} + F_{Pn} \quad [5]$$

As a second step, the determination of the centre of the force is carried out analogously to the design during cutting. In contrast to simple cutting, the position of each individual punch and the position of centre of mass of the sum of the individual cells must be examined during punching and compared with the force diagram. This is necessary, since during punching onto a mould surface, each punch engages with a very high probability at a different point in time, and the load in the cam unit is also introduced in a steplike manner.

The centres of the force are calculated as follows:

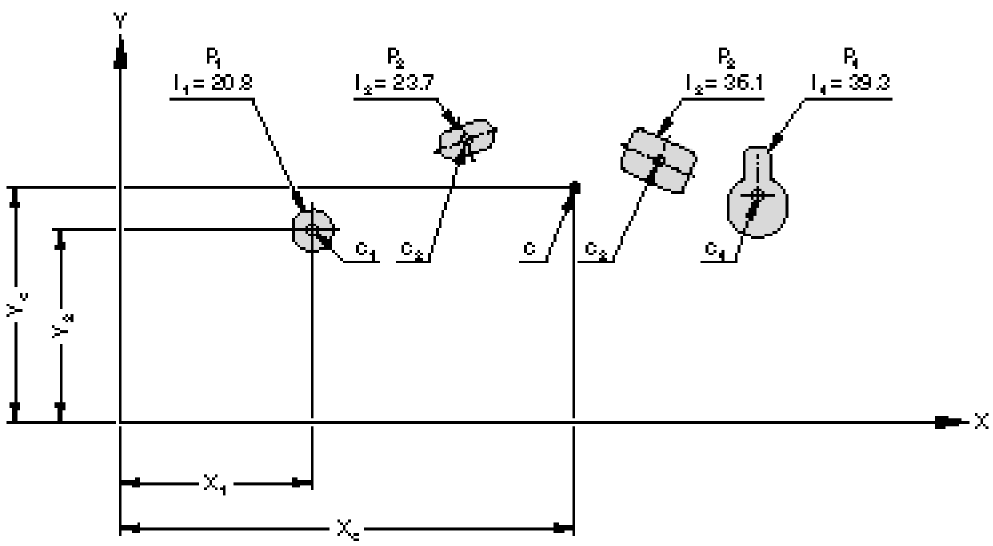


Figure 6: Hole sample

ENGINEERING
CAM UNIT DESIGN

P_1 (round hole) > centre of force in the centre
P_2 (slot) > centre of force in the centre
P_3 (square hole) > centre of force in the centre
P_4 (shaped hole) > determination of the centre by calculating the line centre

In the determination of the total centre of the force of a punching field, the individual cutting lengths of each punch are replaced by the punching forces. The total centre point of the punch field can thus be determined from the individual centre positions:

x value:

$$x_C = (x_1 \times F_{P1} + x_2 \times F_{P2} + x_n \times F_{Pn}) / (F_{P1} + F_{P2} + F_{Pn}) \quad [6]$$

y value:

$$y_C = (y_1 \times F_{P1} + y_2 \times F_{P2} + y_n \times F_{Pn}) / (F_{P1} + F_{P2} + F_{Pn}) \quad [7]$$

Boundary conditions of this calculation model:

In the consideration, a uniform punch engagement of each individual punch is assumed, which is the exception due to the component shape. Tilt and bending of the mould surfaces cause a delayed plunging of the punches. The cutting force reduction by these geometric effects is not taken into account in this calculation model.

The load is changed by the use of a stripper. This must be taken into account in the cam design (see section d)

c) Forming

The term "forming" includes all operations that cause a ductile, permanent form change of the component. The following work operations belong to the forming operating mode:

- Chamfering
- Adjustment
- Postforming
- Drawing

The force required for moulding depends on the shape and the material characteristics. Forming operations on vehicle components are usually complex due to the free form of the components and produce a multi-axial state of stress. The determination of the forces required for this purpose is only possible with difficulty or only with a disproportionate effort. The moulding forces occurring can usually be determined by a drawing simulation. Hard die spotting ("drive to final pressure" / "run against block") with the cam unit is to be avoided if possible. By insufficient coordination of this operation, forces can be introduced into the cam, which exceed the permissible maximum of the allowed operating load by a multiple. Thereby, an immediate failure of the cam unit is possible.

d) Operations with additional stripper

An additional force is introduced into the cam by the use of a stripper resp. cam pad. It is to be taken into account accordingly.

Strippers are used as a stripper plate or as an elastomer / pop-on stripper. The calculation of the centre of force of both variants differs.

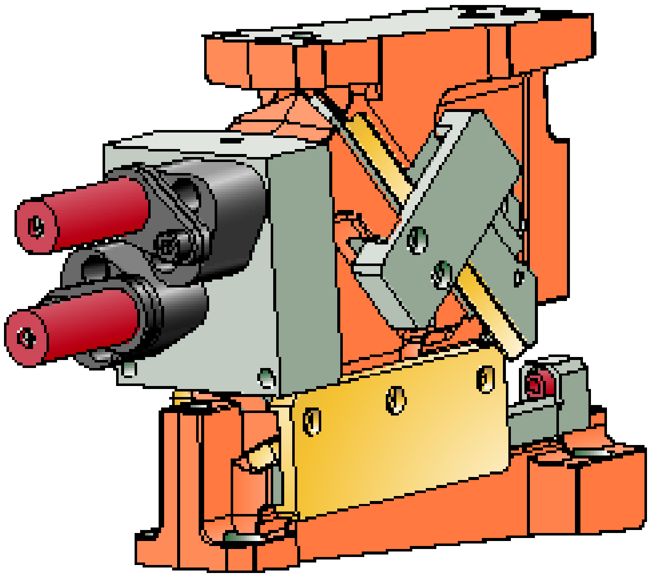


Figure 7: Cam unit with elastomer stripper

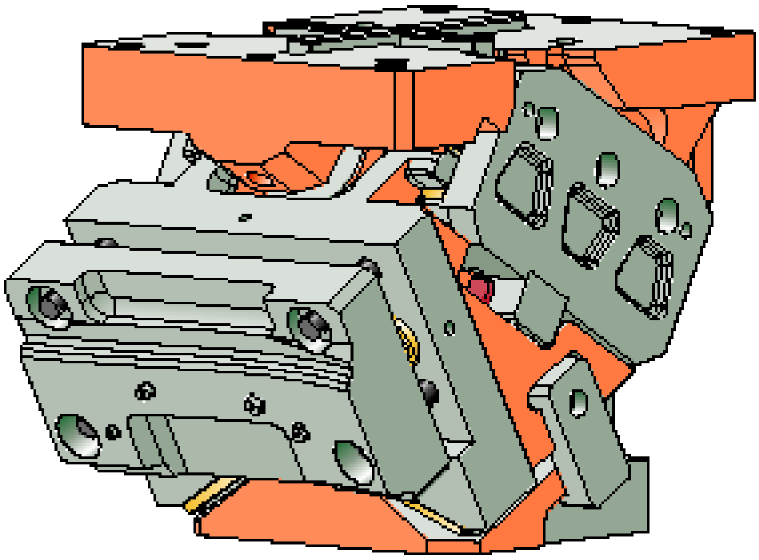


Figure 8: Cam unit with stripper plate

ENGINEERING
CAM UNIT DESIGN

d.1) Elastomer-/Pop-on stripper

Elastomer / Pop-on strippers are extremely compact stripper units, which are directly attached to the supporting plate of a punch. By this arrangement, the centre of mass of an elastomer / pop-on stripper element is centred on the centre axis of the punch.

The total operating force corresponds to the sum of the cutting and stripping force. The centre of mass is then calculated analogous to punching.

d.2) Stripper plate

The centre of the force produced by the stripper plates, in contrast to elastomer / pop-on strippers, is not coincident with the centre of mass force of the working operation. If working with a stripping plate, both the total centre of force of the working operation + stripper plate as well as the centre of force of the stripping plate alone must be compared with the permissible operating force of the cam. This is due to the fact that the load of the stripper plate continues to be present after the fall of the operating force, for example, after punching through the sheet, until the stripper springs are released while opening the die.

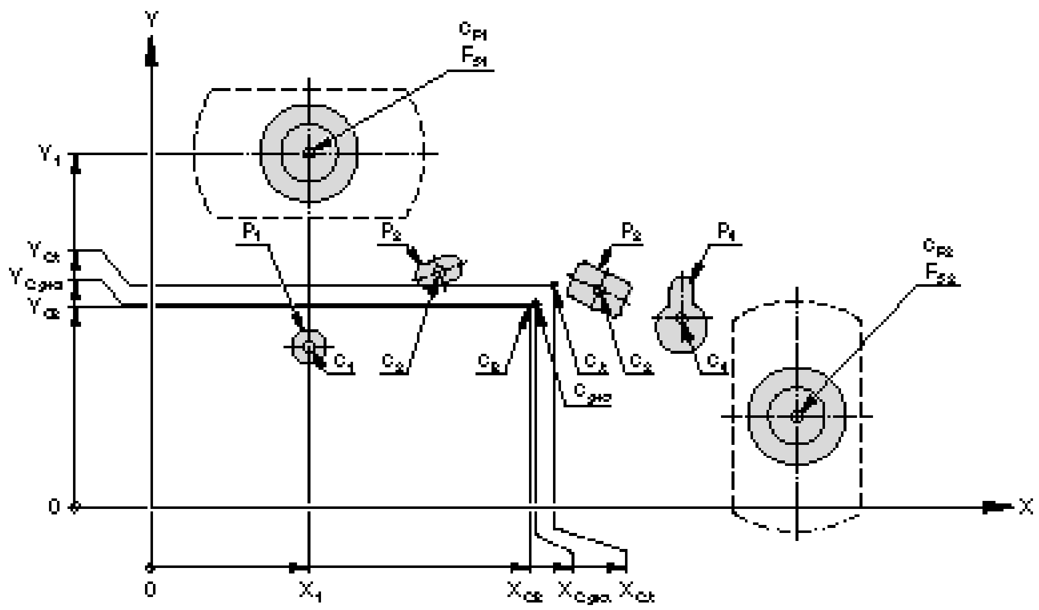


Figure 9: Hole pattern with gas spring

ENGINEERING
CAM UNIT DESIGN

Centre of force of the elastomer / pop-on stripper:

x value:

$$x_{CA} = (x_1 \times F_{S1} + x_2 \times F_{S2} + x_n \times F_{Sn}) / (F_{S1} + F_{S2} + F_{Sn})$$ [8]

y value:

$$y_{CA} = (y1 \times F_{S1} + y_2 \times F_{S2} + y_n \times F_{Sn}) / (F_{S1} + F_{S2} + F_{Sn})$$ [9]

Total centre of operating force and stripper force:

x value:

$$x_{Ctotal} = (x_{CA} \times \text{Sum } F_S + x_{CB} \times F_B) / (\text{Sum } F_S + F_B)$$ [10]

y value:

$$y_{Ctotal} = (y_{CA} \times \text{Sum } F_S + y_{CB} \times F_B) / (\text{Sum } F_S + F_B)$$ [11]

ENGINEERING
PROOF OF LIFETIME

The lifetime test is carried out by comparing the existing operating force with the maximum operating force permitted for the guaranteed lifetime. This results in the statement whether or not the cam unit with the introduced force reaches the guaranteed lifetime.

Cutting

The calculated operating force in the determined centre of the force is compared with the permissible operating force from the force diagram of the desired cam unit. The cam unit maintains the guaranteed lifetime if

$$F_B \leqq F_{zul} \quad [12]$$

Punching

When punching, each individual punch Pn must be compared with its centre of mass Cn, as well as the sum of all punches with the total centre of the force point, with the force diagram of the desired cam unit. The cam unit maintains the guaranteed lifetime if

$$F_{Bn} \leqq F_{zul} \quad [13]$$

and

$$F_{Btotal} \leqq F_{zul} \quad [14]$$

Forming

The operating force determined from the drawing simulation and applied at the centre of the force point is compared with the permissible operating force from the corresponding force diagram. The cam unit maintains the guaranteed lifetime if

$$F_B \leqq F_{zul} \quad [15]$$

Stripper with cam stripper plate

When a cam stripper plate is used, the sum of the operating force + stripping force, with its associated centre of the force point, as well as the stripping load alone, must be compared with its centre of the force point with the force diagram. The cam unit maintains the guaranteed lifetime if

$$F_A + F_B \leqq F_{zul} \quad [16]$$

and

$$F_A \leqq F_{zul} \quad [17]$$

General instructions

- The force specifications of the individual force diagram sectors must never be added.
- The substitute force with the corresponding centre of the force point must always be formed in accordance with the preceding descriptions and these must be compared with the force diagram.
- The specifications in the force diagram correspond to the punctually introduced substitute loads and are not surface pressure specifications!

General notes on permissible operating force

As a matter of principle, the transverse loads acting on the cam unit are to be absorbed by design measures in the tool. Uncompensated transverse loads can have a massively negative effect on the cam unit lifetime.

ENGINEERING
RETRACTION AND RETURN FORCE

Determined by the tension conditions and resulting elastic deformations in the machined sheet metal, cutting and forming components stick after the machining process when the bottom dead centre is reached. Accordingly, a stripping force is required to pull the tools out of the sheet into the initial position. For the design of tools, an approximate calculation of the stripping forces, based on experience values, is sufficiently accurate. The stripping force is calculated as a percentage of the working force.
For cutting operations, this amounts to:

$F_A = 0.07 \times F_T$ [valid for open cutting contours] [18]

$F_A = 0.10 \times F_T$ [valid for closed cutting contours] [19]

In the case of forming operations, the stripping forces vary to a greater degree. When determining the stripping forces during forming operations, the instructions of the tool manufacturers or operators must be observed.

Cam units have a system-related retraction capability. This can be used to overcome the necessary stripping force. If the retraction capacity of the cam unit is higher than the necessary stripping force, no tool-specific actions need to be taken to return the die components to the initial position. In this case, the cam unit can work directly through the main pad of the die.

$F_R > F_A$ [20]

If the retraction capacity of the cam unit is less than the tool- or process-specific stripping force, then constructional measures need to be provided, such as the use of a cam stripper.

$F_R < F_A$ [21]

The retraction force specifications of all FIBRO cam units refer to the working direction of the cam unit, thus, a conversion is not necessary.

If an aerial cam unit remains in its bottom dead centre after the working operation, considerable damage to the cam unit and die is to be expected due to collision of die components while opening it.
In contrast, if a die mounted cam remains in its bottom dead centre after the working operation, then no profound damage is to be expected in the event that the cam does not operate through the main pad. As a rule, the die mechanism in this case is not able to remove the blank out of the die, which stops the movement of the machine by means of the mechanisation sensor system.
If the die components of a die mounted cam also operate through the main pad, similar damage to the cam and die as in the case of an aerial cam unit is to be expected.
Please note that for this reason, the mechanical retraction clamps must not be removed without consulting with FIBRO.

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The design for die construction is illustrated by the following three examples.

1. Cutting

a) by main pad

Process parameters:
Cam unit angle 40°
greatest width of the cutting line on cam 278 mm
Cutting contour see figure
Length l = 305.9 mm
Sheet metal thickness s = 0.7 mm
Material DX51D+Z; max. tensile strength R_m = 270...500 N/mm²
open cutting line: Stripping force 7% of cutting force

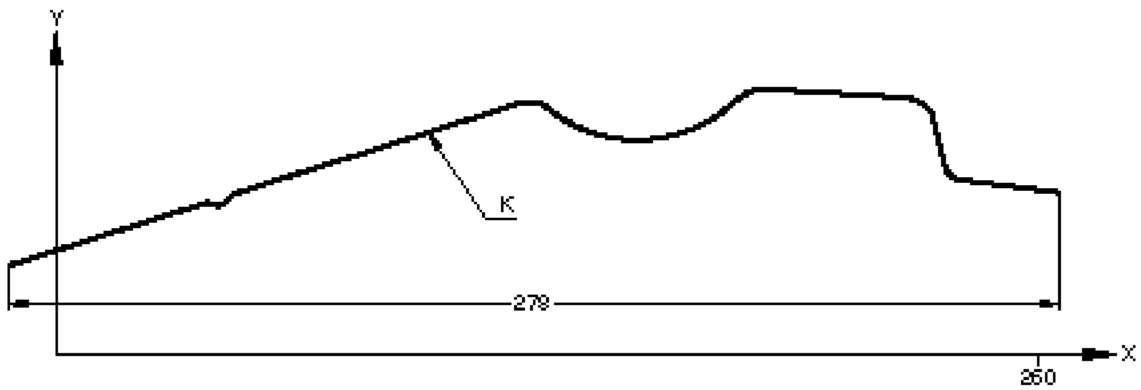

Figure 10: Cutting contour

Determination cutting force F_T (= Operating load F_B)

$F_T = l \times s \times \delta_T = l \times s \times R_m \times 0.8$

F_T = 305,9 mm × 0.7 mm × 500 N/mm² × 0.8

F_T = 85.7 kN

Determination stripping force F_A

$F_A = F_T \times 0.07$

F_A = 85.7 kN × 0.07

F_A = 6 kN

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Determination of centre of the force C_F

The cutting contour is segmented into the replacement cutting contour, compare figure. The mass centres of the individual segments of the replacement cutting contour are known.
For the calculation of the total centre of the force, the zero point of the coordinate system is assumed to be x + 12.5 / y - 23.5 measured from the left outermost corner of the cutting contour. The lengths, as well as single centre of mass values of the individual contours are as follows (graphically determined values):

No.	Type	Length contour element (mm)	x_C (mm)	y_C (mm)
1	Line	146.7	57.4	45.7
2	Arc	62.8	155.6	61.1
3	Line	48	207.1	69.1
4	Line	21.8	233.7	57
5	Line	29.4	250.9	44.7

The position of the total centre of the force is calculated from the values of the individual segments:

$$\mathbf{x_C = (x_1 \times l_1 + x_2 \times l_2 + x_3 \times l_3 + x_4 \times l_4 + x_5 \times l_5) / (l_1 + l_2 + l_3 + l_4 + l_5)}$$
$$x_C = (57.4\ \text{mm} \times 146.7\ \text{mm} + 155.6\ \text{mm} \times 62.8\ \text{mm} + 207.1\ \text{mm} \times 48\ \text{mm} + 233.7\ \text{mm} \times 21.8\ \text{mm} + 250.9\ \text{mm} \times 29.4\ \text{mm}) / (146.7\ \text{mm} + 62.8\ \text{mm} + 48\ \text{mm} + 21.8\ \text{mm} + 29.4\ \text{mm})$$
$$\mathbf{x_C = 131.5\ mm}$$

$$\mathbf{y_C = (y_1 \times l_1 + y_2 \times l_2 + y_3 \times l_3 + y_4 \times l_4 + y_5 \times l_5) / (l_1 + l_2 + l_3 + l_4 + l_5)}$$
$$y_C = (45.7\ \text{mm} \times 146.7\ \text{mm} + 61.1\ \text{mm} \times 62.8\ \text{mm} + 69.1\ \text{mm} \times 48\ \text{mm} + 57\ \text{mm} \times 21.8\ \text{mm} + 44.7\ \text{mm} \times 29.4\ \text{mm}) / (146.7\ \text{mm} + 62.8\ \text{mm} + 48\ \text{mm} + 21.8\ \text{mm} + 29.4\ \text{mm})$$
$$\mathbf{y_C = 53.2\ mm}$$

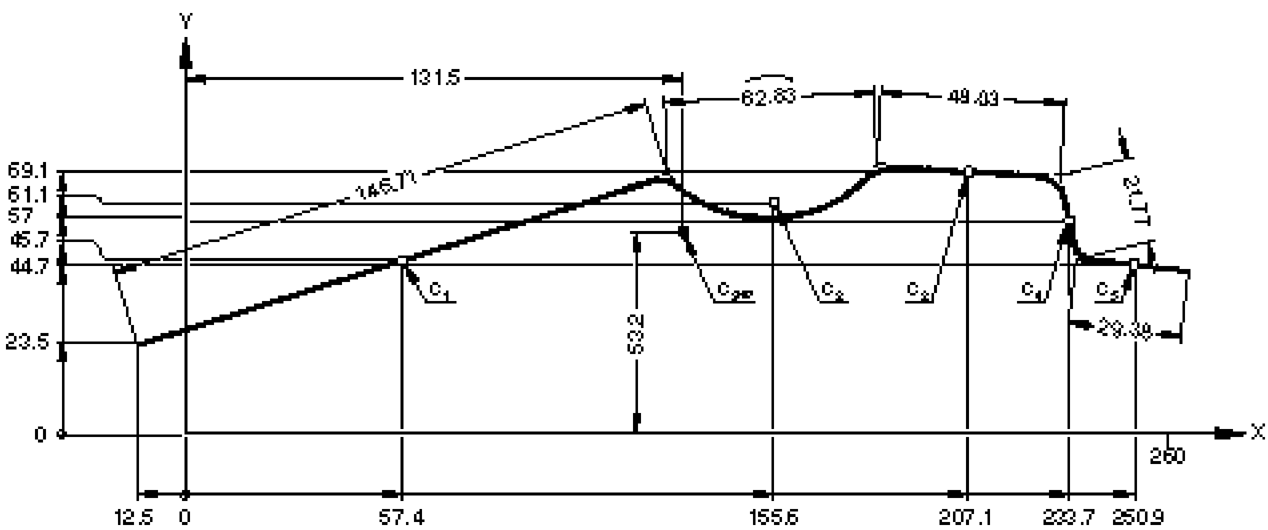

Figure 11: Cutting contour approximated

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The determined force values are compared with the performance data of the selected cam unit. For this work operation, an aerial cam unit of the 2016.24. series with a working width of 260 mm is to be used. The cam unit has the following performance data:

max. working force (shouldered installation):	737 kN
max. working force (installation with feather key):	359 kN
Retraction force:	36.4 kN

The total centre of force of the cam cut is on the quadrant of the force diagram with 737 kN permissible load (shouldered) or 320 kN permissible load (installed with feather key). The cam unit can therefore be installed with the given cutting contour and the applied process parameters both with the force relief via a shoulder on the rear side of the cam base as well as via the feather key inserted into the cam base supporting surface in the die:

$F_T < F_{permissible\ feather\ key} < F_{permissible\ shoulder}$

85.7 kN < 320 kN < 737 kN

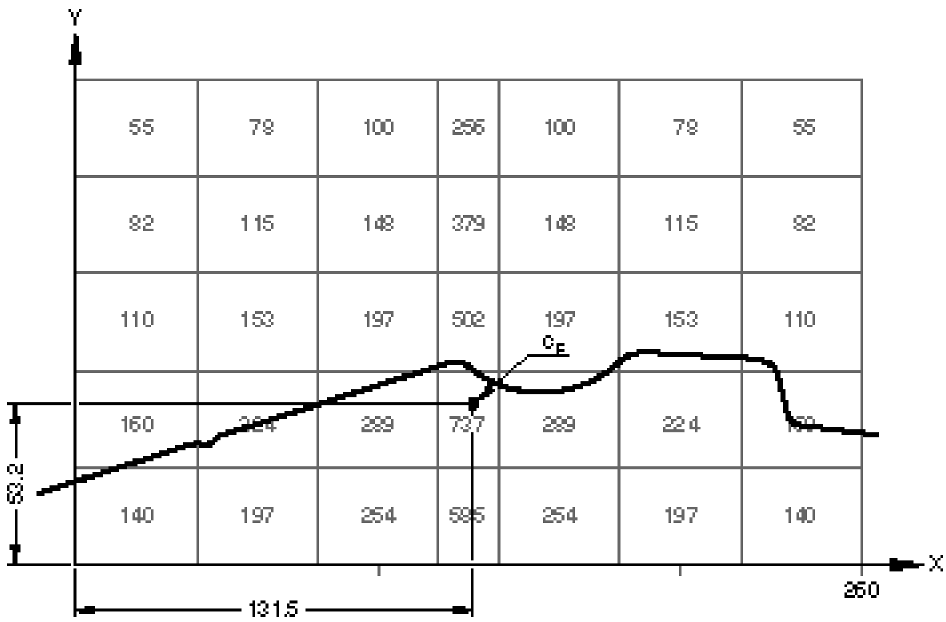

Figure 12: Cutting contour with force diagram

No further actions have to be taken to move the cam unit back in the initial position when the press is opened – the retraction force of the cam unit is higher than the process-induced stripping force:

$F_R > F_A$

33.6 kN > 6 kN

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2. Punching

a) by main pad

Process parameters: Cam unit angle 15°
largest distance between punch centres is 72.6 mm
Punch contours, see figure
Contour lengths and individual centres of the force, see table
Sheet metal thickness s = 1.5 mm
Material D750MS /+Z; max. tensile strength R_m = 1,000...1,200 N/mm^2
closed cutting line: Stripping force 10% of cutting force

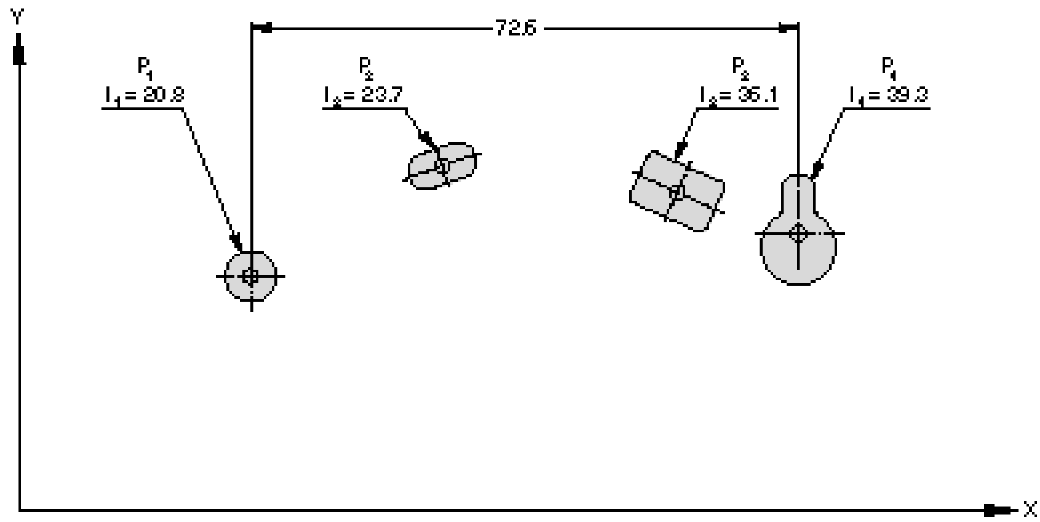

Figure 13: Hole pattern with size estimation

Determination cutting force during punching F_{Pn} (= Operating force F_B)

$$F_P = l \times s \times \delta T = l \times s \times R_m \times 0.8$$

Punch P_1:
F_{P1} = 20.9 mm × 1.5 mm × 1,200 N/mm^2 × 0.8
F_{P1} = 30.1 kN

Punch P_2:
F_{P2} = 23.8 mm × 1.5 mm × 1,200 N/mm^2 × 0.8
F_{P2} = 34.3 kN

Punch P_3:
F_{P3} = 36.1 mm × 1.5 mm × 1,200 N/mm^2 × 0.8
F_{P3} = 52 kN

Punch P_4:
F_{P4} = 39.3 mm × 1.5 mm × 1,200 N/mm^2 × 0.8
F_{P4} = 56.6 kN

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Total cutting force F_{Ptotal} during punching:

$F_{Ptotal} = F_{P1} + F_{P2} + F_{P3} + F_{P4}$

F_{Ptotal} = 30.1 kN + 34.3 kN + 52 kN + 56.6 kN

F_{Ptotal} = **173 kN**

Determination stripping force F_A

$F_A = F_{Ptotal} \times 0.1$

F_A = 173 N × 0.1

F_A = **17.3 kN**

Determination of the total centre of the force

The centres of the force of the individual punches are known. For the calculation of the total centre of the force, the zero point of the coordinate system is assumed to be x + -26.6 / y - 31.2 measured from the centrepoint of the punch P_1. The positions of the individual centre of the force values result from the method plan as follows (graphically determined values):

No.	Type	Length (mm)	x_C (mm)	y_C (mm)
P_1	Round hole	20.8	26.6	31.2
P_2	Slot	23.7	51.8	45.9
P_3	Square hole	36.1	83.2	42.5
P_4	Keyhole	39.3	99.3	36.1

The position of the total centre of the force is calculated from the values of the individual punches:

$x_C = (x_1 \times F_{P1} + x_2 \times F_{P2} + x_3 \times F_{P3} + x_4 \times F_{P4}) / (F_{P1} + F_{P2} + F_{P3} + F_{P4})$

x_C = (26.6 mm × 30.1 kN + 51.8 mm × 34.3 kN + 83.2 mm × 52 kN + 99.3 mm × 56.6 kN) / (30.1 kN + 34.3 kN + 52 kN + 56.6 kN)

x_C = **72.4 mm**

$y_C = (y_1 \times F_{P1} + y_2 \times F_{P2} + y_3 \times F_{P3} + y_4 \times F_{P4}) / (F_{P1} + F_{P2} + F_{P3} + F_{P4})$

y_C = (31.2 mm × 30.1 kN + 45.9 mm × 34.3 kN + 42.5 mm × 52 kN + 36.1 mm × 56.6 kN) / (30.1 kN + 34.3 kN + 52 kN + 56.6 kN)

y_C = **39.1 mm**

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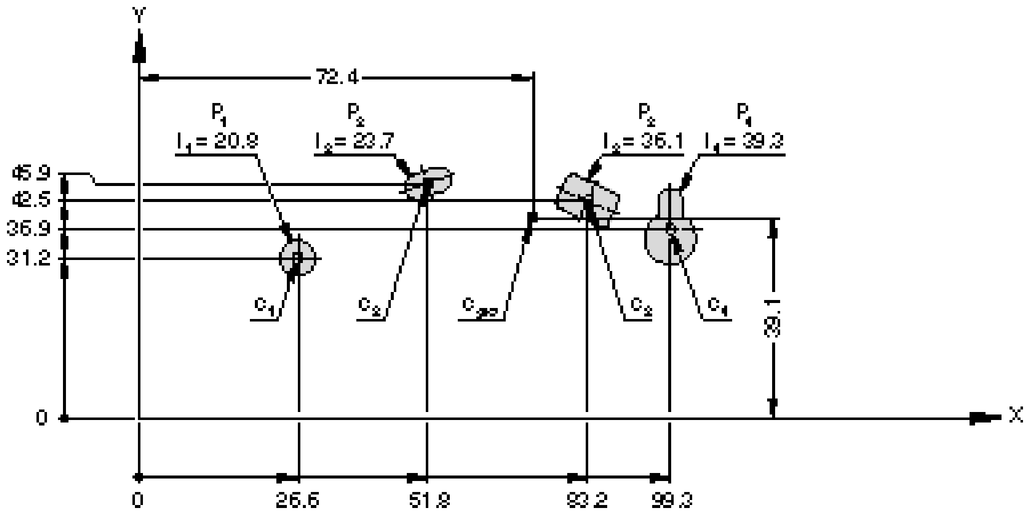

Figure 14: Hole pattern with individual centre of mass

The determined force values are compared with the performance data of the selected cam unit. For this work operation, preferably, a compact aerial cam unit of the 2016.24. series is to be used.
Due to the maximum distance of about 72.6 mm of the centre of mass of the holes, an attempt is made to use a cam unit with a width of 110 mm and a multi-punch retainer plate.

The selected cam unit has the following performance data:

- max. working force (shouldered installation): 372 kN
- max. working force (installation with feather key): 93 kN
- Retraction force: 5.8 kN

The total centre of the force of the hole pattern is on the quadrant of the force diagram with 372 kN permissible load (shouldered) or 80 kN permissible load (installed with feather key). Therefore, the process forces on the cam should absolutely be absorbed by a shoulder on the back of the cam base for the given hole pattern and its process parameters:

$F_{\text{permissible feather key}} < F_P < F_{\text{permissible shoulder}}$
80 kN < 173 kN < 372 kN

The individual centres of the force of each punch lie on quadrants of the force diagram in each case with a higher permissible load than the present operating force. A stepped punching caused by the partial shape thus does not cause any unacceptable overloads on the cam unit. In the following, only the forces with the force diagrams installation type "shouldered" are compared:

Punch P_1:
30.1 kN < 91 kN

Punch P_2:
34.3 kN < 164 kN

Punch P_3:
52 kN < 164 kN

Punch P_4:
56.6kN < 164kN

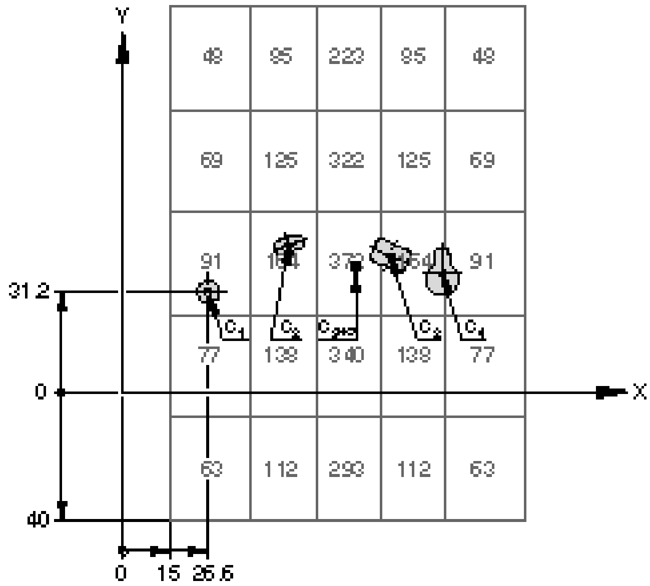

Figure 15: Hole pattern with force diagram

The constructional retraction force of the cam is not sufficient to move the slider back into the initial position while the press opens; the return force of the cam is less than the process-induced stripping force:

$\mathbf{F_R < F_A}$
5 kN < 17.3 kN

Die specific actions must be taken in order to ensure that the slider can be returned.
In this case, a cam stripper is used.

b) with gas-spring-operated cam stripper

The cam from point a) is equipped with a gas-spring-operated cam stripper to increase the retraction force. It has to be operated by two or three compact gas springs of the POWERLINE series. According to the design, approx. 12 kN retraction force is missing for a smooth process. Springs of the POWERLINE series with a cylinder diameter of 38 mm have an initial force of 5 kN. For the present case, three springs are thus required for the actuation of the cam pad. The springs are mounted using a square mounting flange. The additional installation space required for this is to be taken into account when selecting the cam unit. As a result of the flange dimensions, the width of the slider working surface must be at least 147 mm. Accordingly, the next largest cam unit width is selected with 150 mm. With approx. 8 kN, this cam unit has a greater retraction capacity than the originally selected cam unit with a width of 110 mm. With this cam unit and the selected gas springs, two pieces are sufficient to actuate the cam stripper. In order to be able to accommodate the guide, retaining and safety elements on the cam unit work surface, to obtain a good distribution of the force introduction, and to realise a compact overall space, the springs are arranged diagonally on the working surface (compare illustration).

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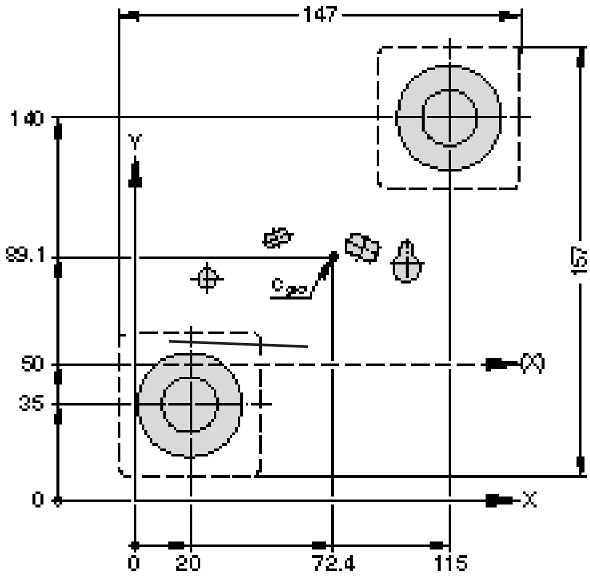

Figure 16: Hole pattern with stripper plate

Determination of the centre of the force of the stripper plate.

Shifted by 50 mm in the y-direction for the calculation, the original reference system:

$$\mathbf{x_{CA} = (x_1 \times F_{S1} + x_2 \times F_{S2}) / (F_{S1} + F_{S2})}$$
$$x_{CA} = (20\text{ mm} \times 5\text{ kN} + 115\text{ mm} \times 5\text{ kN}) / (5\text{ kN} + 5\text{ kN})$$
$$\mathbf{x_{CA} = 67.5\text{ mm}}$$

$$\mathbf{y_{CA} = (y_1 \times F_{S1} + y_2 \times F_{S2}) / (F_{S1} + F_{S2})}$$
$$y_{CA} = (35\text{ mm} \times 5\text{ kN} + 140\text{mm} \times 5\text{ kN}) / (5\text{ kN} + 5\text{ kN})$$
$$\mathbf{y_{CA} = 87.5\text{ mm}}$$

Determination of the total centre of the force hole pattern + stripper plate

$$\mathbf{x_{Ctotal} = (x_{CA} \times \Sigma F_S + x_{CB} \times F_B) / (\Sigma F_S + F_B)}$$
$$x_{Ctotal} = (67.5\text{ mm} \times 10\text{ kN} + 72.4\text{mm} \times 173\text{ kN}) / (10\text{ kN} + 173\text{ kN})$$
$$\mathbf{x_{Ctotal} = 72.1\text{ mm}}$$

$$\mathbf{y_{Ctotal} = (y_{CA} \times \Sigma F_S + y_{CB} \times F_B) / (\Sigma F_S + F_B)}$$
$$y_{Ctotal} = (87.5\text{ mm} \times 10\text{ kN} + 89.1\text{mm} \times 173\text{ kN}) /(10\text{ kN} + 173\text{ kN})$$
$$\mathbf{y_{Ctotal} = 89.0\text{ mm}}$$

The additional cam stripper does not cause any unacceptable operating states. Both the force of each punch, the total force of all punches with their centre of the force, the force of the cam stripper with its centre of the force as well as the total force of all the forces acting with the total centre of the force lie within the permissible forces of the respective quadrant of the cam diagram. The cam must be installed shouldered in the die.

ENGINEERING
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$\sum F_S < F_{\text{permissible feather key}} < F_{\text{permissible shoulder}}$
10 kN < 110 kN < 439 kN

$F_{\text{permissible feather key}} < F_{\text{total}} < F_{\text{permissible shoulder}}$
110 kN < 183 kN < 439 kN

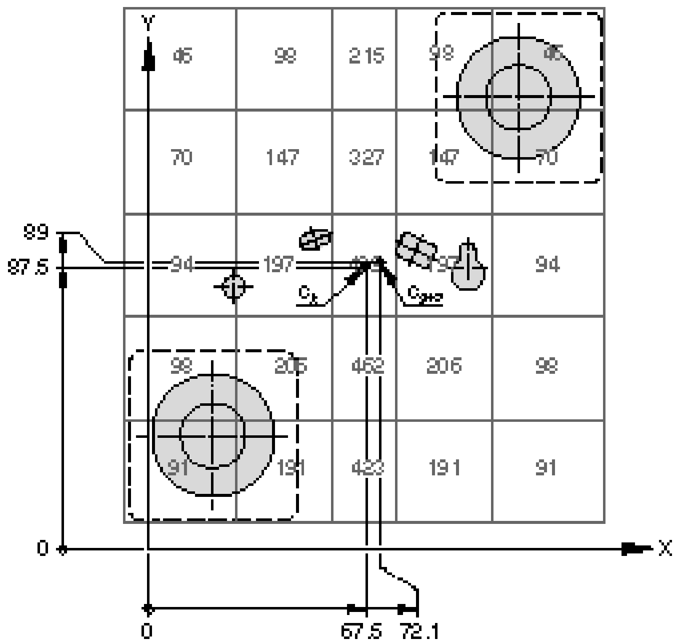


Figure 17: Hole pattern with stripper plate and force diagram

The sum of the retraction force of the cam and stripper is sufficient to move the cam back into the initial position while the press opens:

$F_R > F_A$
18 kN > 17.3 kN

ENGINEERING
LOAD-OPTIMISING MEASURES

Constructive actions can reduce or compensate operating and secondary loads (e.g. transverse forces). These actions may have effects on the quality of the press part or the manufacturing process. Therefore they have to be coordinated with the operator of the die.

a) Modified trim steel geometry

In the case of a simultaneous trim steel engagement over the entire cutting length, the cutting work is performed over the path of the sheet thickness. The cutting work is calculated from:

$$W_T = F_T \times t$$

If the trim steel geometry is designed in the form of a shear, a roof or a wave, the working path is extended analogous to the selected trim steel shape. The performed cutting work W_T remains unchanged in its size, therefore the necessary cutting force F_T becomes lower.

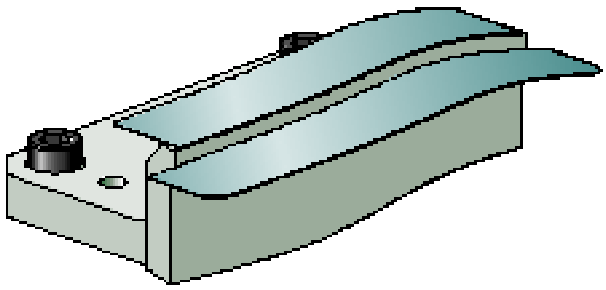


Figure 18: Trim steel with parallel grinding

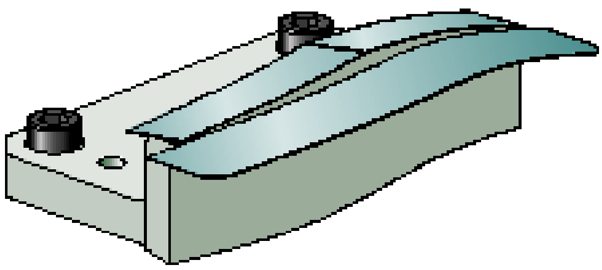


Figure 19: Trim steel with top grinding

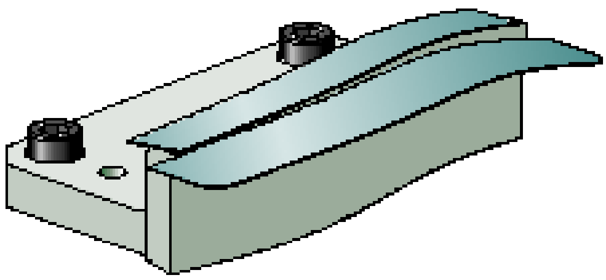


Figure 20: Trim steel with scissors grinding

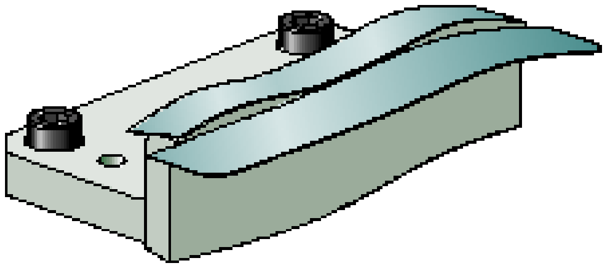


Figure 21: Trim steel with wave grinding

The cutting force can be reduced up to 50% by means of a cutting force reducing design. Due to the geometrically altered design of the trim steels the centre of the force may also vary during the cutting process. A quantitative statement about the centre of the force progression is difficult to determine with trim steels shaped in this way. Due to cam load it's recommended to design the force-optimised trim steels symmetric.

For aluminium press parts, these cutting force reducing actions are not recommended. They can cause uncontrollable, inadmissible process fluctuations here.

ENGINEERING
LOAD-OPTIMISING MEASURES

b) Absorption of transverse forces

Transverse forces cause additional loads on the cam unit components. They add up vectorially to the operating force in the cam direction and thus have a significant influence on the cam unit lifetime. Therefore transverse forces must be compensated by constructive measures in the die in order to prevent system overload. The absorption of the transverse force is preferably performed parallel to the working engagement at the same height.

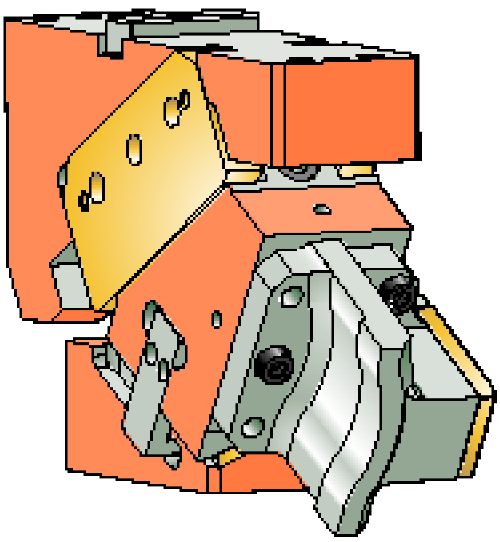


Figure 22: Absorption of transverse force

A simple description of the relationship between the transverse force and the lifetime is not possible since the permissible transverse force depends on the direction of action and the magnitude of the operating force.

C) Dimensioning of the protrusion

Large tool protrusions over the work surface have an influence on the working result, the system load and the lifetime of the cam unit due to geometric and static effects:

- high weight load on cam unit system due to large tool fittings on the work surface
- Multiplication of the effect by transverse forces due to lever mechanisms
- noticeably faster influence on the work result by lever effect through possible changes in the clearance
- changed damping behaviour

In general, you should therefore endeavour to achiev the smallest possible protrusion in the working area. Standard punching lengths (including retainer plate) + approx. 50 mm can be assumed as a guide.
Overhangs in front of the working surface, which go beyond this guideline, are also possible, but must be checked and evaluated in the course of the die design. FIBRO is pleased to advise and support you.

ENGINEERING
LOAD-OPTIMISING MEASURES

d) Application of compensatory forces

In the case of eccentric operating forces, the total force distribution can be positively influenced by introducing compensating forces. Appropriately dimensioned springs are arranged on the work surface for this purpose, which act against the lower die or against the mounted main pad. Through the use of compensating forces, the total force as well as the total centre of the force change. Accordingly, compensating elements must be taken into account during the course of the cam unit design.

Compensation elements behave analogously to slider strippers. Their force continues to be applied after the end of the working process, for example, after cutting through the sheet metal. The centre of the force of the compensating forces must therefore also be compared with the permissible cam forces in order to make a sound statement about the applied cam force possible (solution path, see chapter "Cam stripper").

Example:

The following values are known for one application case:

Process parameters	cam unit:	2016.24.150.015.1000.0
	Working width:	150 mm
	Angle:	15°
	Cutting length l_1:	42.7 mm
	Cutting length l_2:	54.5 mm
	Punch contours + possible arrangement, see figure	
	Sheet metal thickness:	1,2 mm
	Tensile strength:	1,000 N/mm^2

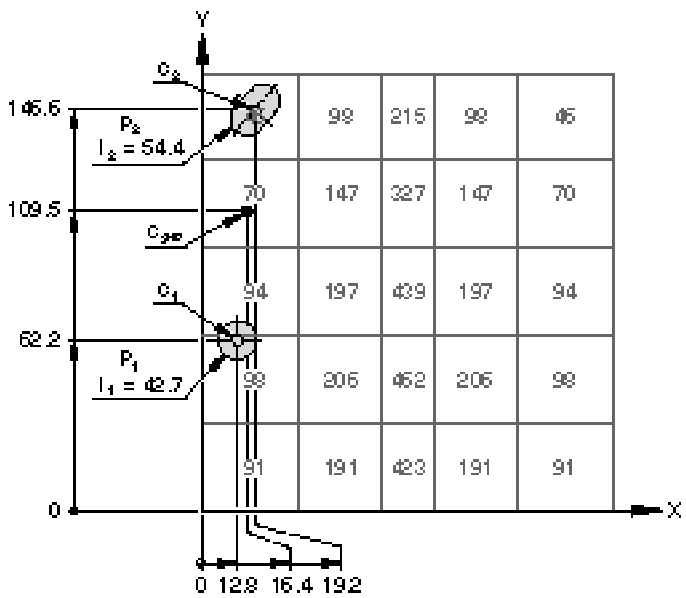


Figure 23: Eccentric hole pattern

ENGINEERING
LOAD-OPTIMISING MEASURES

The forces and centres of the force are as follows:

F_{P1} = 41.0 kN / x_{C1} = 12.8 mm / y_{C1} = 62.2 mm
F_{P2} = 52.2 kN / x_{C2} = 19.2 mm / y_{C2} = 146.6 mm
F_{Ptotal} = 93.2 kN / x_{Ctotal} = 16.4 mm / y_{Ctotal} = 109.5 mm

The forces of the cam unit are absorbed by means of a solid cast shoulder on the back of the cam base. Accordingly, the proof of lifetime results after comparison of the forces with the cam load diagram:

$F_{P1} < F_{zul}$
41 kN < 98 kN -> Loading by punch P_1 permissible

$F_{P2} > F_{zul}$
52.2 kN > 46 kN -> Loading by punch P_2 not permissible

$F_{Ptotal} > F_{zul}$
93.2 kN > 70 kN -> Loading by load sum not permissible

Corresponding to the calculation results, constructive countermeasures must be provided in order to avoid overloading and thus a reduced lifetime of the cam unit. The centre of the force of the punch P2 as well as the total centre of the force must be moved further towards the middle of the cam unit. For this purpose, a compensating spring is to be provided on the working surface of the cam which acts against the main pad of the die:

Selected spring: FIBRO 2487.12.02400.016 (POWERLINE)
Spring nominal force: 24 kN
Mounting position x/y: 105 mm / 62.2 mm

By means of this additional spring, the total centre of the force point of the punch P2 and of the spring is shifted to the following coordinates:

$F_{Compensation}$ = 72,6 kN / $x_{Ccompensation}$ = 46,2 mm / $y_{Ccompensation}$ = 120 mm

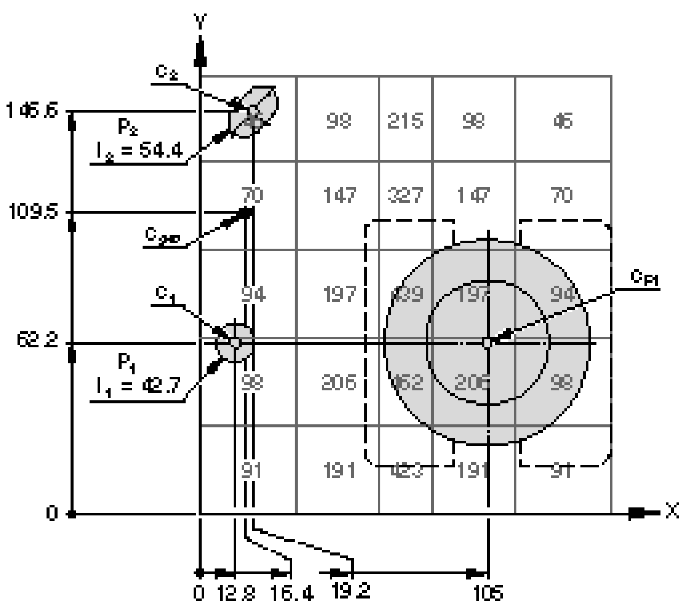


Figure 24: Eccentric hole pattern with compensation spring

ENGINEERING
LOAD-OPTIMISING MEASURES

With this arrangement, the proof of lifetime no longer produces inadmissible operating conditions:

$F_{Compensation} < F_{permissible}$
76.2 kN < 147 kN -> Loading by punch P_2 permissible

$F_{S1} < F_{permissible}$
24 kN < 206 kN -> The loading of the compensation spring after the end of the cutting process is permissible.

The solution must be coordinated with the die operator.

ENGINEERING
PROTRUSION BOX

Lateral protrusions beyond the cam unit work surface should generally be avoided - a wider cam unit is the better choice in these application cases. If a lateral protrusion can not be avoided for certain reasons, the following aspects must be ensured to guarantee the desired lifetime:

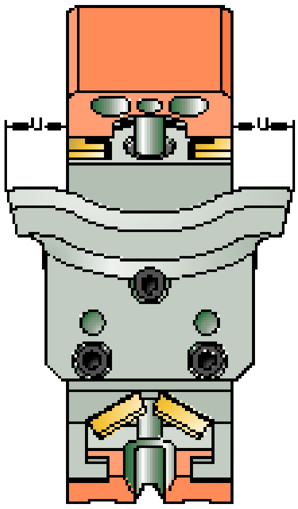
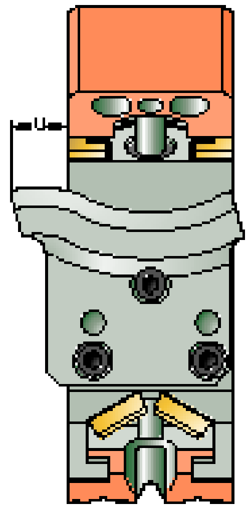
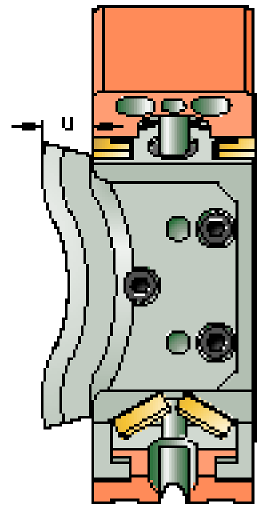
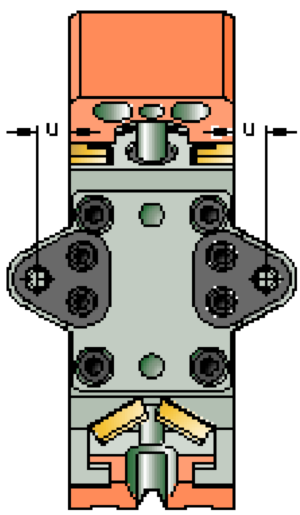
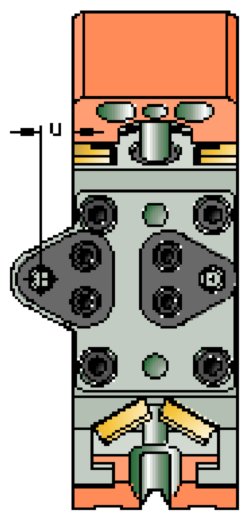
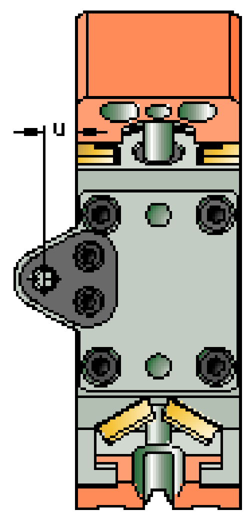
1. The total working force must not exceed the maximum permissible working force of the cam unit.

2. Asymmetrically arranged elements on the cam unit cause a shift of the centre of the force. The position of the centre of the force must be taken into account and adjusted with the permissible values according to the force diagram.

3. In the case of multiple hole operations on free-form surfaces, it is generally assumed that the hole punches enter the sheet at different times. Punches arranged eccentrically or in the protrusion of the cam work surface require a particularly precise design.

The tool length on cam units also has a significant influence on the system load and the working result of the cam unit. Long protrusions should be avoided whenever possible due to a weaker bending stiffness of the tools and a large lever effect.

ENGINEERING
PROTRUSION BOX

	unrestricted or partially permissible		not permitted
Cutting + forming	 Figure 25: Trim steel, Protrusion centric	 Figure 26. Trim steel, Protrusion one-sided horizontal	 Figure 27: Trim steel, Protrusion one-sided vertical
Punching*	 Figure 28. Hole pattern, Protrusion centric	 Figure 29. Hole pattern, Protrusion one-sided	 Figure 30. Punch, Protrusion one-sided

* Observe engagement point in time of the punches

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