Geometric displacement volume and flow in the phase of a two-phase hydraulic converter

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Abstract: The paper researches the possibilities to replace the parallel flow hydraulic mechanisms in agricultural machinery with hydraulic units with fluid alternating flow as they provide more efficient operation due to their output alternating motion. The method being presented analyses how the geometric displacement volume in the fluid alternating piston converter is created. This is basically achieved by adding or omitting elements in the phase which consequently reduces the quantity of converter types being manufactured.

Keywords: geometric displacement volume; alternating flow; two-phase mechanism

Extensive employment of hydrostatic mechanisms goes hand in hand with increasing demands on hydrostatic converters and introducing their most advanced designs into respective fields of industry. Apart from conventional parallel flow hydraulic sets, units with the alternating fluid flow proved their significance in the practice. In conventional parallel flow sets, the fluid flows in the line between the hydraulic pump and the hydraulic motor in one direction. On the other hand, the operating fluid makes a reverse motion in mechanisms with the alternating flow. It means that both flow and pressure are periodical in its stabilized condition (Tkáč *et al.* 2004; Koreisová 2005). Since the motion of the converter's active element (e.g. piston) is harmonic, so is the flow behavior in the phase.

Despite the fact that there are several kinds of mechanisms with fluid alternating flow as for the number of phases (lines), extensive application of two-phase units with fluid alternating flow (FAF) is expected. Two-phase mechanisms with the fluid alternating flow have been widely spread and used in agriculture, shipping and handling industry, civil engineering, mining etc. Thus, they can be used in any equipment requiring alternating harmonic motion (Jurčo 1997). Some features that make them so distinct from conventional cam or crank units include easy to follow installation and simple overload protection.

The paper presents the method creating geometric displacement volume in the piston converter phase with the fluid alternating flow and its subsequent flow in the phase.

MATERIAL AND METHODS

A various number of elements can be used to create a phase in a two-phase rotary converter. Let us have an axial piston swash plate type hydrostatic pump having four elements (pistons) in a phase (Figure 1). The aforementioned elements are arranged at a specific α angle alongside the pitch circle in a regular manner. If rationalized this arrangement may, however, be irregular. This is for example when the hydraulic motor necessitates the non-sine flow in the course of the technological process. It has to be provided though that the geometric displacement volumes during phases share the same angle of rotation ϕ. If the geometric displacement volumes differ in phases, then it must be true, that the geometric displacement volumes of the hydraulic pump and hydraulic motor phases can be expressed by the formula $V_{G1} = V_{M1}$ and $V_{B2} = V_{M2}$ (Nevrlý 2005).

The phase can differ in the number of elements. Figure 2 shows axial piston converters having one to eight elements in the phase. All the pistons are interconnected in one phase. Geometric displacement

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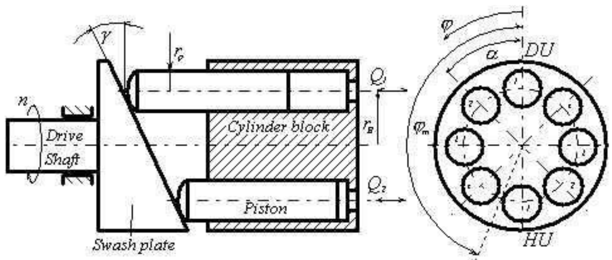

Figure 1. Axial piston swash plate type hydraulic pump having one phase consisting of four elements (pistons); *HU* – Top Dead Centre, *DU* – Bottom Dead Centre, n – speed, γ – swash plate axial deflection, r_p – piston radius, r_B – pitch circle radius of the cylinder bloc, $Q_{1,2}$ -flow in the phase 1,2

volume in one phase can also be made by omitting some elements.

Let us assume that the first piston starts moving at the bottom dead point. Then, the i^{th} piston stroke can be obtained from the following formula (Turza *et al.* 2005; Lahučký 2005):

$$x_{pi} = h_p \times [1 - \cos(\phi - \alpha_i)] \qquad (1)$$

where:

h_p – i^{th} piston stroke from one dead point to the other

$$h_{pi} = 2 \times r_B \times \tan(\gamma) \qquad (2)$$

ϕ is the shaft tilt angle from the bottom dead point *DU* of the piston at the constant angular speed of the shaft ω_B

$$\phi = \omega_B \times t = 2\pi \times n \times t \qquad (3)$$

where:

γ – swash plate axial deflection,

r_B – radius of the circle of the cylinder block,

t – time,

ω_B, n – angular speed and shaft speed,

α_i – angle of the i^{th} piston to the first one in the phase having in total $i = z$ number of pistons in a phase.

As shown by Eq. (1), the motion is harmonic. When differentiating Eq. (1), we will obtain the gradual velocity of the i^{th} piston.

$$v_{pi} = \frac{dx_{pi}}{dt} = v_{p0} \times \sin(\phi - \alpha_i) \qquad (4)$$

where a piston maximum velocity (velocity amplitude) is

$$v_{p0} = \omega_B^2 \times r_B \qquad (5)$$

Flow by one i^{th} piston motion can be expressed by the formula

$$Q_{pi} = S_p \times v_{pi} \qquad (6)$$

where the piston cross-section is

$$S_p = \pi \times r_p^2 \qquad (7)$$

where r_p means piston radius.

This requires identical both cross-section of all pistons and single piston flow behavior, however, the phase is shifted by α value.

In case z pistons are arranged in a phase alongside the pitch circle in a regular manner, r_B denoting its radius, then the angle of the i^{th} piston to the first one is

$$\alpha_i = (i - 1) \times \pi / z \qquad (8)$$

By Eq. (6), the flow from z pistons in the phase will be

$$Q = S_p \times \sum_{i=1}^{z} v_{pi} \qquad (9)$$

The sum of all velocities by Eq. (9) and using Eq. (4) will be

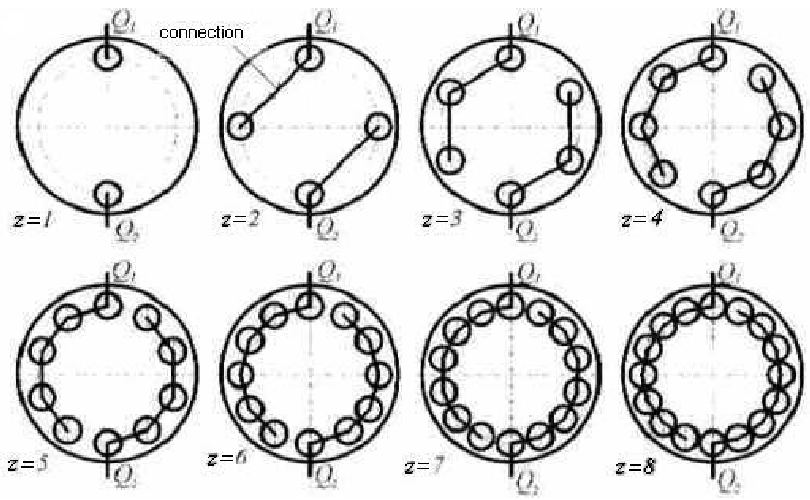

Figure 2. Axial piston converters, a phase consisting of one to eight elements, z – number of elements; $Q_{1,2}$ – flow in the phase

$$\sum_{i=1}^{z} v_{pi} = v_{p0} \times \sum_{i=1}^{z} \sin(\varphi - \alpha_i) \quad (10)$$

Let us use the following formula to calculate the flow in the phase having $z = 4$ pistons in a phase. Then, the sum on the right-hand side in Eq. (10) will take the form

$$\sum_{i=1}^{4} \sin(\varphi - \alpha_i) = \sin(\varphi) + \sin(\pi/4) + \sin(\pi/2) + \sin(3\pi/4) \quad (11)$$

Let us use the familiar equation for the sum of angles

$$\sin(\varphi - \alpha_i) = \sin(\varphi) \times \cos(\alpha_i) - \cos(\varphi) \times \sin(\alpha_i) \quad (12)$$

After substituting Eq. (12) to Eq. (11) and subsequent modification, we get

$$\sum_{i=1}^{4} \sin(\varphi - \alpha_i) = \sin(\varphi) - (1 + \sqrt{2}) \times \cos(\varphi) \quad (13)$$

An extreme value will be obtained for Eq. (13), if derivation according φ makes 0. Thus, we get

$$\frac{d}{d\varphi}[\sin(\varphi) - (1 + \sqrt{2}) \times \cos(\varphi)] = \cos(\varphi_m) + (1 + \sqrt{2}) \times \sin(\varphi_m) \quad (14)$$

where $\varphi = \varphi_m$ is the shaft tilt angle reaching the maximum flow.

By modified Eq. (14), we obtain

$$a\tan(\varphi_m) = -(1 + \sqrt{2}) \quad (15)$$

By Eq. (15), we obtain the value of the shaft tilt angle providing the maximum flow

$$\varphi_m = 7/8\pi = 157.5° \quad (16)$$

When substituting the value φ_m from Eq. (16) that makes an extreme value of the function in Eq. (13), an extreme value of the function can be obtained. It is actually the amplitude of the resulting flow behavior (resulting velocity)

$$A_Q = \sin(\varphi_m) - (1 + \sqrt{2}) \times \cos(\varphi_m) = \sin(7\pi/8) - (1 + \sqrt{2}) \times \cos(7\pi/8) = 2.61312593 \quad (17)$$

Provided that the function by Eq. (13) makes zero,

$$\sin(\varphi) - (1 + \sqrt{2}) \times \cos(\varphi) = 0 \quad (18)$$

we can calculate the first angle value $\varphi = \beta$ according to the sequence expressing the phase shift of the resulting flow in the phase

$$\tan(\beta) = (1 + \sqrt{2}) \Rightarrow \beta = 3/8\pi = 67.5° \quad (19)$$

Then, the resulting flow behavior according to Eq. (9) takes the form of

$$Q = S_p \times v_{p0} \times A_Q \times \mathit{sin}\,(\varphi - \beta) \quad (20)$$

Figure 3 shows the unit flow behavior for individual pistons having $z = 4$ pistons in the phase as well as for individual angles. Unit flow behaviors are obtained from the modified relations in Eq. (6) and (20) taking the form of

$$Q_i^* = \frac{Q_{pi}}{S_p \times v_{p0}} = \sin(\varphi - \alpha_i) = \sin(\varphi - \frac{i-1}{4} \times \pi) \quad (21)$$

and

$$Q^* = \frac{Q}{S_p \times v_{p0}} = A_Q \times \mathit{sin}\,(\varphi - \beta) = 2.61312593 \times \sin(\varphi - \frac{3}{8} \times \pi) \quad (22)$$

If we make the relations for z pistons general, following will be obtained for the two-phase mechanism:
angle for pistons in the phase

$$\alpha = \pi/z \quad (23)$$

i^{th} piston angle to the bottom dead point

$$\alpha_i = (i - 1) \times \pi/z \quad (24)$$

Table 1. Parameters for various number of elements in the cylinder block in an axial piston converter

Variable	Number of elements in the z phase							
	1	2	3	4	5	6	7	8
Amplitude A_Q	1.0	$2^{0.5}$ 1.414214	2.0	2.613126	3.236068	3.83637	4.493952	5.342228
$\alpha = \pi/z$	π 180°	π/2 90°	π/3 60°	π/4 45°	π/5 36°	π/6 30°	π/7 25.7143°	π/8 22.5°
$\beta = [(z - 1)/ 2z] \times \pi$	0 0°	π/4 45°	π/3 60°	3·π/8 67.5°	2·π/5 72°	5π/12 75°	3·π/7 77.143°	7·π/16 78.75°
$\varphi_m = [(2z - 1)/ 2z] \times \pi$	0 0°	3·π/4 135°	5·π/6 150°	7·π/8 157.5°	9·π/10 162°	11·π/12 165°	13·π/14 167.143°	15·π/16 168.79°

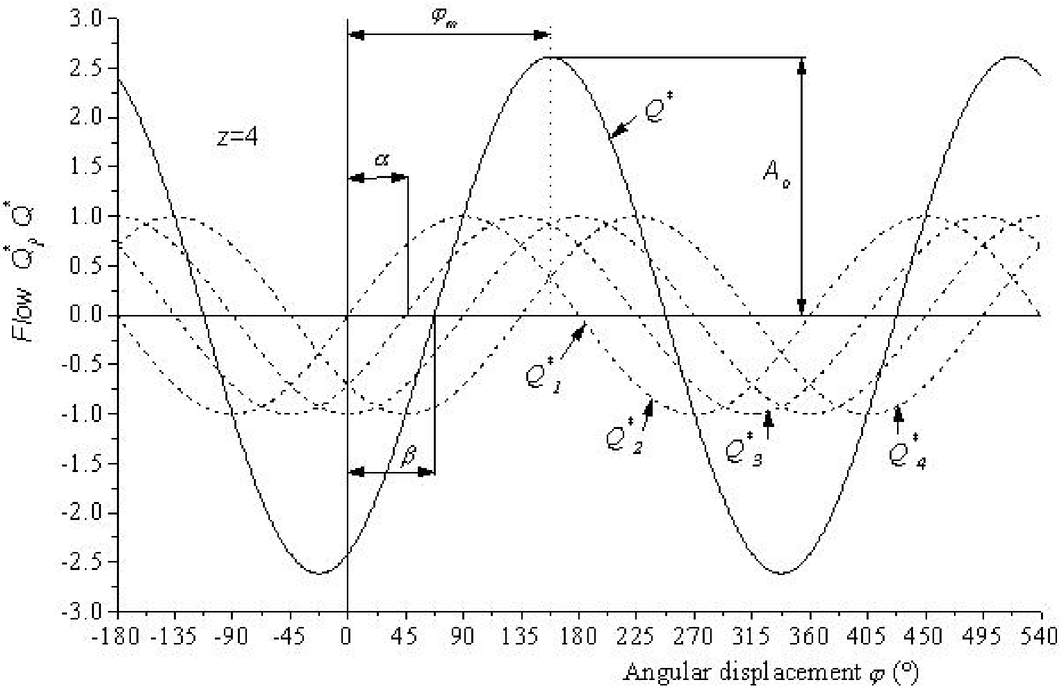

Figure 3. Behavior of the relative flows for z = 4 elements in the phase; Q^* – resulting relative flow , Q^*_1 - relative flow of the j element, α – flow phase displacement of the j element, β – phase displacement of the resulting flow, ϕ_m – angle of the resulting glow maximum amplitude

phase shift of the resulting phase flow

$$\beta = \frac{z-1}{2z} \times \pi \tag{25}$$

maximum flow amplitude will be calculated as aforementioned (Table 1 provides figures for as many as 8 pistons),
angle at which the maximum value of the resulting flow in the phase is reached

$$\phi_m = \frac{2z-1}{2z} \times \pi \tag{26}$$

single element flow behavior in the phase derived from Eq. (6)

$$Q_{pi} = S_p \times v_{p0} \times \sin(\phi - \alpha_i) \tag{27}$$

flow behavior in the phase derived from Eq. (9)

$$Q = S_p \times v_{p0} \times A_Q \times \sin(\phi - \beta) \tag{28}$$

that corresponds with Eq. (20).

We will use the following formula to calculate the resulting flow amplitude

$$A_Q = \sum_{i=1}^{z} \sin\left(\frac{2z-2i+1}{2z} \times \pi\right) \tag{29}$$

RESULTS

Table 1 provides a comprehensive list of angles and amplitudes for individual resulting flows having z = 1 to z = 8 pistons in the phase.

Figure 4 shows behavior of both the resulting flow amplitude in the phase and angles as conditioned by how many elements there are in a phase. As shown in the diagram, the amplitude does not represent a direct product of the number of elements in the phase. Let us make an example – for z = 3 elements, the amplitude does not make 3, but 2. The angles among elements in the α phase, the phase shift of the resulting flow in the β phase as well as ϕ_m angle at which the maximum value of the resulting flow with various number of pistons in the phase are given.

Figures 5–9 show relative flow behaviors as provided by individual pistons as well as resulting flows in the phase for z = 2, 3, 5, 6, and 7 pistons in the phase.

To make comparisons, Figure 10 shows the resulting flows for a different number of elements in the phase.

Given any number of elements z, it is possible to interconnect the opposite elements in phases with those being part of a phase to create further combinations with different flow amplitudes.

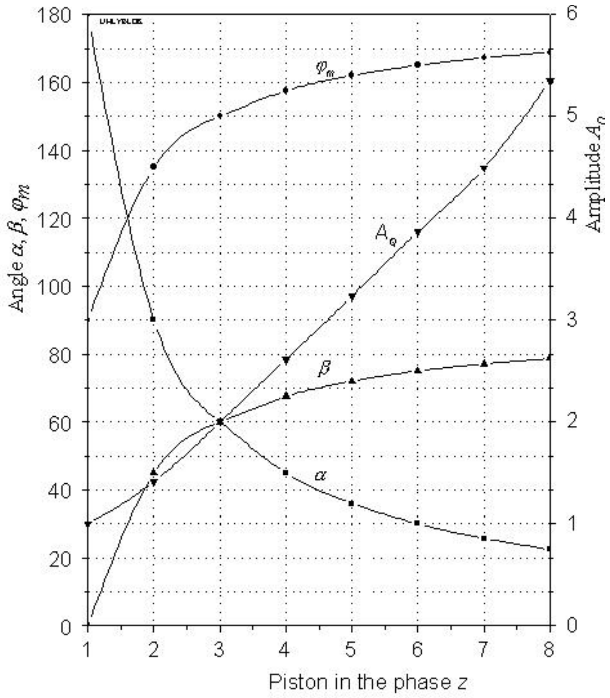

Figure 4. The amplitude behavior of the relative resulting flow and angles taking into account the number of pistons in the phase z; A_Q – the resulting flow amplitude, α – the flow phase displacement of the i element, β – the resulting flow phase displacement, ϕ_m – maximum amplitude angle of the resulting flow

Let there be two elements (pistons) in the phase as shown in Figure 11. It is possible to make four combinations if connecting opposite elements in phases with those being part of a phase. Combination types 2 and 3 are equal when considering the amplitude. However, the phase shift against the first element has been changed. Phase 1 is shifted by angle phase compared to combinations 1 and 2. It is a common practice to replace the combination type 4 in any circuit by shorting the phases by means of a distributor (Prikkel 2002; Pavlok 2004).

Table 2 shows values of A_Q amplitude, β phase shift as well as the angle that proves the maximum flow. Figure 5 shows behaviors of both individual flows and resulting flow consisting of z = 2 number of pistons in the phase. When applying combination No. 1, flow in the phase will be expressed in terms of

$$Q_1 = S_p \times v_{p0} \times A_{Q1} \times \sin(\phi - \beta_1) = S_p \times v_{p0} \times 1.4142136 \times \sin(\phi - \pi/4) \quad (30)$$

When applying combination No. 2, the flow in the phase will be expressed in terms of

$$Q_2 = S_p \times v_{p0} \times A_{Q2} \times \sin(\phi - \beta_2) = S_p \times v_{p0} \times \sin(\phi) \quad (31)$$

When applying combination No. 3, the flow in the phase will be expressed in terms of

$$Q_3 = S_p \times v_{p0} \times A_{Q3} \times \sin(\phi - \beta_3) = S_p \times v_{p0} \times \sin(\phi - \frac{\pi}{2}) \quad (32)$$

and finally, we will apply combination No. 4

$$Q_4 = 0 \quad (33)$$

In reality, it is feasible to make two combinations of flow sizes based on the maximum flow amplitude. It is advisable to opt for combinations No. 1, 2 and 4 because when switched, the lowest phase shift β is obtained.

Let there be three elements (pistons) in the phase. Figure 6 shows the basic behavior of the elements flow and the resulting flow in the phase. It is possible to make eight combinations if connecting opposite elements in phases with those being part of the phase. Figure 12 provides a detailed listing of the combinations possible. There is one combination

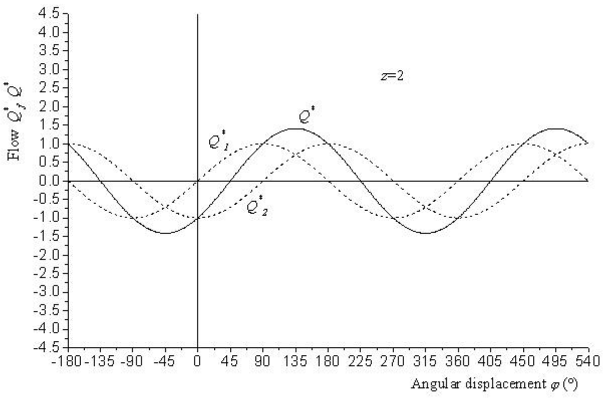

Figure 5. Single piston relative flow behaviors and the resulting flow in the phase for z = 2 pistons; Q_j^* – relative flow of the j element, Q^* – resulting relative flow

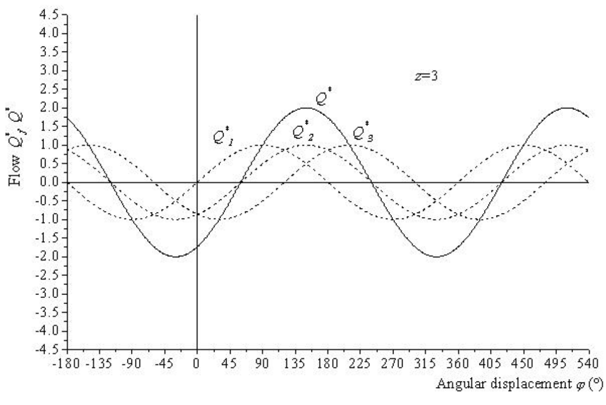

Figure 6. Single piston relative flow behaviors and the resulting flow in the phase for z = 3 pistons; Q^* – the resulting relative flow, Q_j^* – relative flow of the j element

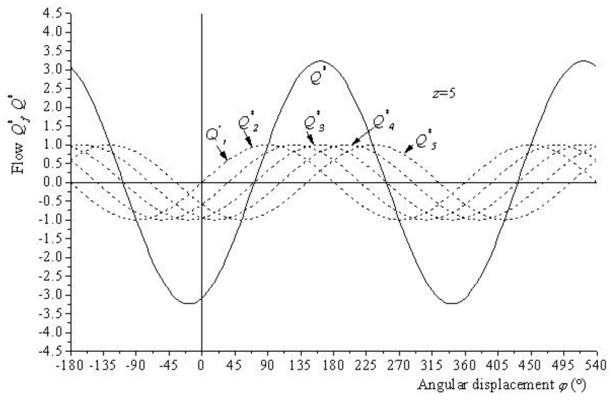

Figure 7. Single piston relative flow behaviors and the resulting flow in the phase for $z = 5$ pistons; Q^* – the resulting relative flow, Q^*_j – relative flow of the j element

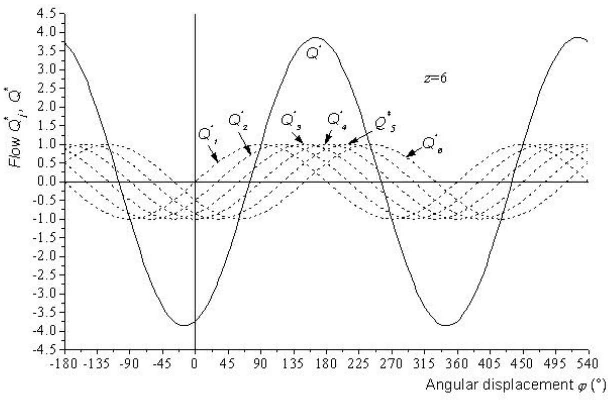

Figure 8. Single piston relative flow behaviors and the resulting flow in the phase for $z = 6$ pistons; Q^* – the resulting relative flow, Q^*_j – relative flow of the j element

No. 1, type *A*. Combinations No. 2 and 5, type *B* are equal when considering the amplitude. However, the phase shift against the first element has been changed. There are four combinations No. 3, 4, 6 and 7, type *C*. Similarly, they are equal in terms of the amplitude. However, the phase shift against the first element has been changed. It is usual that the combination No. 8, type *D* is used in any circuit by shorting the phases by means of a distributor.

Table 3 shows the values of A_Q amplitude, β phase shift as well as the angle ϕ_m that proves the maximum flow. When applying combination No. 1, the flow in the phase will be expressed in terms of

$$Q_1 = S_p \times v_{p0} \times A_{Q1} \times \sin(\phi - \beta_1) = S_p \times v_{p0} \times 2.0 \times \sin(\phi - \pi/3) \quad (34)$$

When applying combination No. 2, the flow in the phase will be expressed in terms of

$$Q_2 = S_p \times v_{p0} \times A_{Q2} \times \sin(\phi - \beta_2) = S_p \times v_{p0} \times 1.414214 \times \sin(\phi - \pi/6) \quad (35)$$

Similarly, the remaining combinations flow in a phase will be obtained from the formula

$$Q_j = S_p \times v_{p0} \times A_{Qj} \times \sin(\phi - \beta_j) \quad (36)$$

where *j* denotes the combination number – as shown in Table 3. There are three applicable combinations; one can be used by shorting the phases. The slightest phase shift is attributed to combinations No. 1, 2, 4 and 8.

Let there be four elements (pistons) in a phase. It is possible to make sixteen combinations if connecting opposite elements in phases with those being part of a phase. Figure 13 lists the combination types. There is one combination No. 1, type *A*. Combinations No. 2 and 9, type *B* are equal when

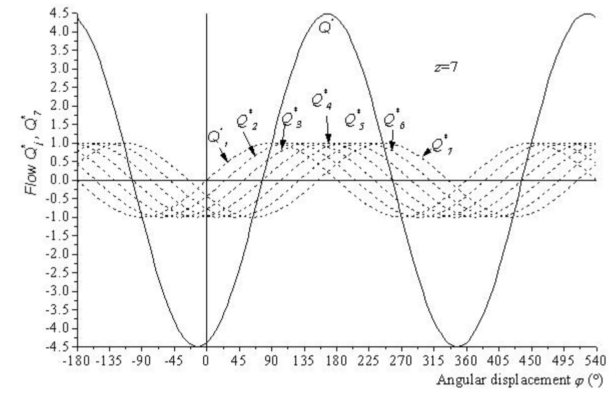

Figure 9. Single piston relative flow behaviors and the resulting flow in the phase for z = 7 pistons; Q^* – the resulting relative flow, Q^*_i – relative flow of the *i* element

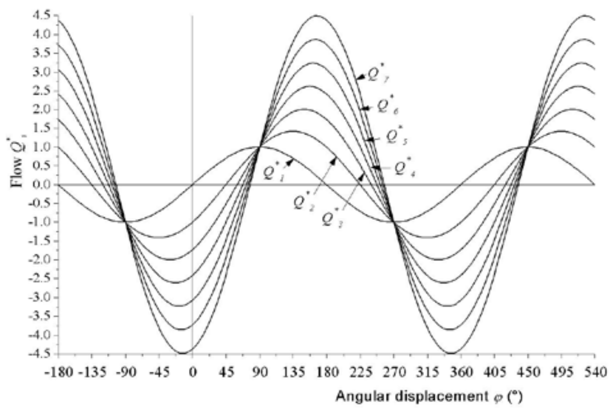

Figure 10. Relative flows reached with z = 1 to z = 7 elements in a phase; Q^*_z – the resulting relative flow for z elements

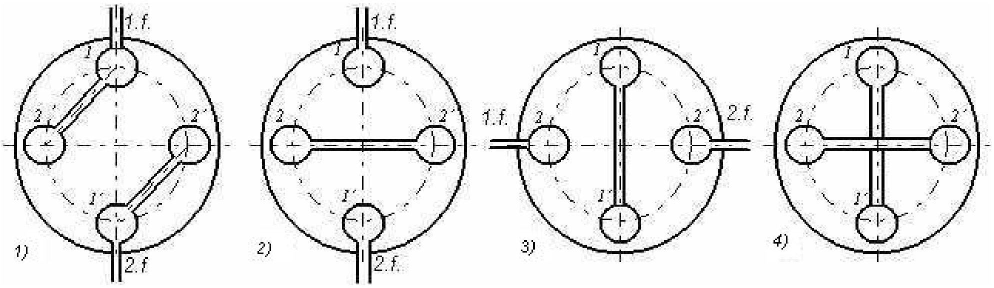

Figure 11. Various combinations of flow amplitude gained by omitting some elements while having z = 2 pistons in the phase; 1, 2 – phase 1 elements, 1´, 2´ – phase 2 elements

considering the amplitude. However, the phase shift against the first element has been changed. There are three combinations No. 4, 10 and 13, type *C*. There are two combinations No. 3 and 5, type *D* and two combinations No. 6 and 11, type *E*. They are equal in terms of the amplitude. However, the phase shift against the first element has been changed. There are four combinations No. 8, 12, 14 and 15, type *F* having the amplitude of one element and a different phase shift. There is one combination No. 7, type *G* having the amplitude lower if compared with the amplitude of one element. The combination provides a different phase shift against the first element. There is one combination No. 16, type *H* and it is usual to be used in any circuit by shorting the phases with a distributor

Table 4 shows the values of A_Q amplitude, β phase shift as well as the angle ϕ_m that proves the maximum flow having z = 4 pistons. Figure 14 shows behavior of individual flows as well as the resulting

Table 2. Combinations available for z = 2 pistons in a phase

No.	Type	Pistons		Amplitude A_Q	Phase shift β	Angle at maximum ϕ_m
		1	2			
1	A	1	1	1.4142136	π/4 = 45°	3·π/4 = 135°
2	B	1	0	1.0	0.0°	π/2 = 90°
3	B	0	1	1.0	π/2 = 90°	2·π = 180°
4	C	0	0	0.0	0.0°	0.0°

β, ϕ_m – in relation to the 1st piston

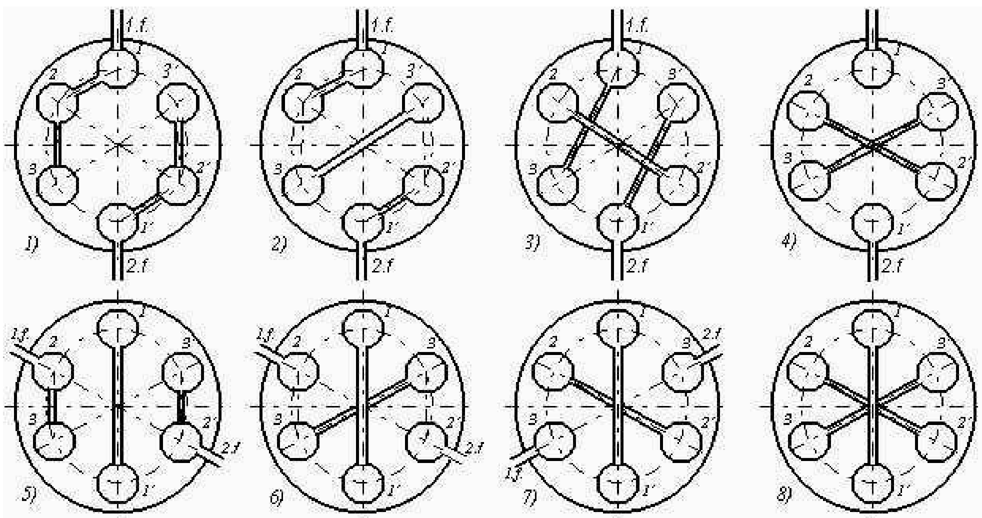

Figure 12. Various combinations of flow amplitude gained by omitting some elements while having z = 3 pistons in the phase; 1–3 – phase 1 elements, 1´–3´ – phase 2 elements

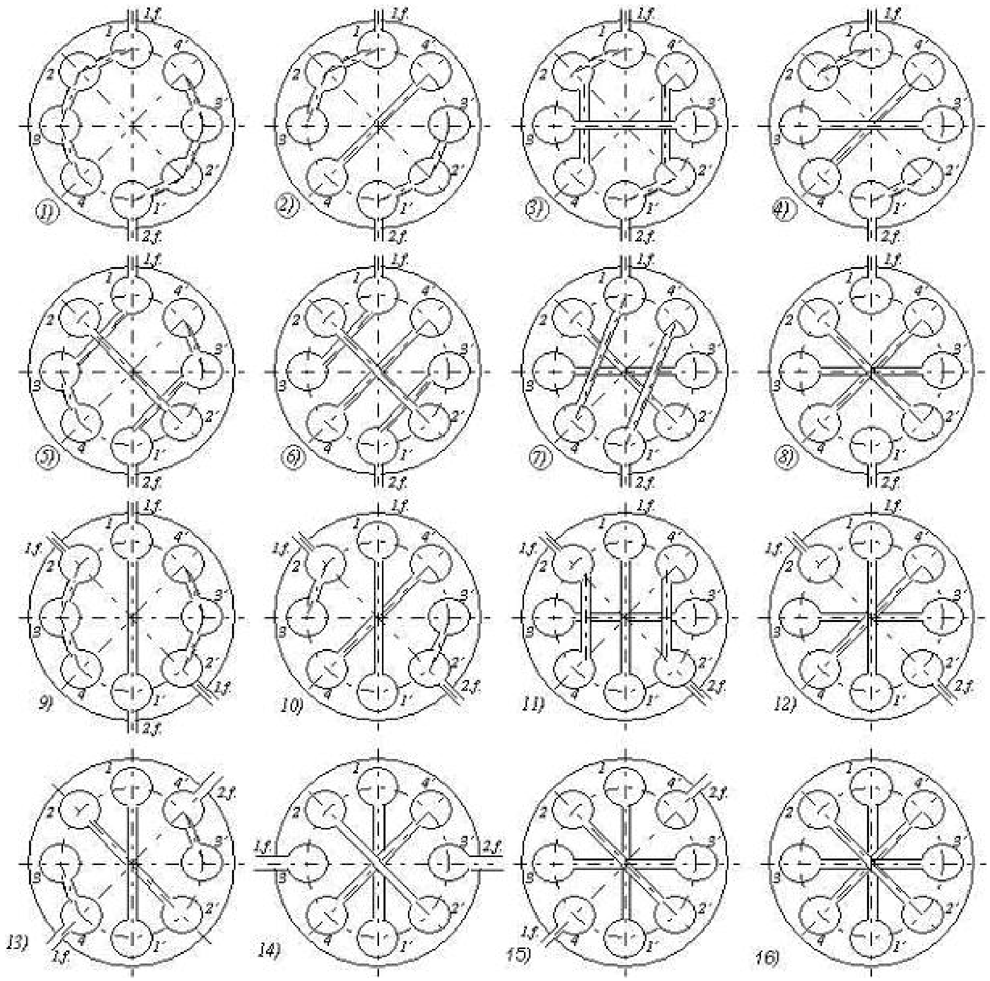

Figure 13. Various possible combinations of the flow amplitude obtained by omitting some elements while having z = 4 pistons in the phase; 1–4 – phase 1 elements, 1´–4´ – phase 2 elements

flow consisting of z = 4 pistons in the phase and combinations available. Behavior of the relative flows takes the form of

$$Q_{pj} = \frac{Q_{4j}}{S_p \times v_{p0}} \qquad (37)$$

where:

j – combination number as shown in Table 4.

It is possible to make eight basic combinations if connecting opposite elements in phases with those

Table 3. Combinations available for z = 3 pistons in a phase

No.	Type	Pistons			Amplitude A_Q	Phase shift β	Angle at maximum ϕ_m
		1	2	3			
1	A	1	1	1	2.0	π/3 = 60°	5·π/6 = 150°
2	B	1	1	0	1.732051	π/6 = 30°	π/3 = 120°
3	C	1	0	1	1.0	π/3 = 60°	5·π/6 = 150°
4	C	1	0	0	1.0	0.0°	π/2 = 90°
5	B	0	1	1	1.732051	π/2 = 90°	π = 180°
6	C	0	1	0	1.0	π/3 = 60°	5·π/6 = 150°
7	C	0	0	1	1.0	π/3 = 120°	7·π/8 = 210°
8	D	0	0	0	0.0	0.0°	0.0°

β, ϕ_m – in relation to the 1st piston

Table 4. Combinations available for z = 4 pistons in a phase

No.	Type	Pistons				Amplitude A_Q	Phase shift β	Angle at maximum ϕ_m
		1	2	3	4			
1	A	1	1	1	1	2.61312593	3·π/8 = 67.5°	7·π/8 = 157.5°
2	B	1	1	1	0	2.414213562	π/4 = 45°	4·π/4 = 135°
3	D	1	1	0	1	1.732050807	atn($2^{0.5}$) = 54.73561032°	144.73561032°
4	C	1	1	0	0	1.847759065	π/8=22.5°	5·π/8=112.5°
5	D	1	0	1	1	1.732050807	80.26438968°	170.26438968°
6	E	1	0	1	0	1.414213562	π/4 = 45°	3·π/4 = 135°
7	G	1	0	0	1	0.765366868	3·π/8 = 67.5°	7·π/8 = 157.5°
8	F	1	0	0	0	1.0	0.0°	π/2 = 90°
9	B	0	1	1	1	2.414213562	π/2 = 90°	π = 180°
10	C	0	1	1	0	1.847759065	3·π/8 = 67.5°	7·π/8 = 157.5°
11	E	0	1	0	1	1.414213562	π/2 = 90°	π = 180°
12	F	0	1	0	0	1.0	π/4 = 45°	3·π/4 = 135°
13	C	0	0	1	1	1.847759065	5·π/8 = 112.5°	9·π/8 = 202.5°
14	F	0	0	1	0	1.0	π/2 = 90°	π = 180°
15	F	0	0	0	1	1.0	3·π/4 = 135°	5·π/4 = 225°
16	H	0	0	0	0	0.0	0.0°	0.0°

β, ϕ_m – in relation to the 1st piston

being part of a phase. They do not share the value of the flow amplitude (Figure 15).

Individual combinations flow in the phase is expressed in terms of

$$Q_{4j} = S_p \times v_{p0} \times A_{Q4j} \times \sin (\sin(\phi - \beta_{4j}) \quad (38)$$

where:

j – combination number as shown in Table 4.

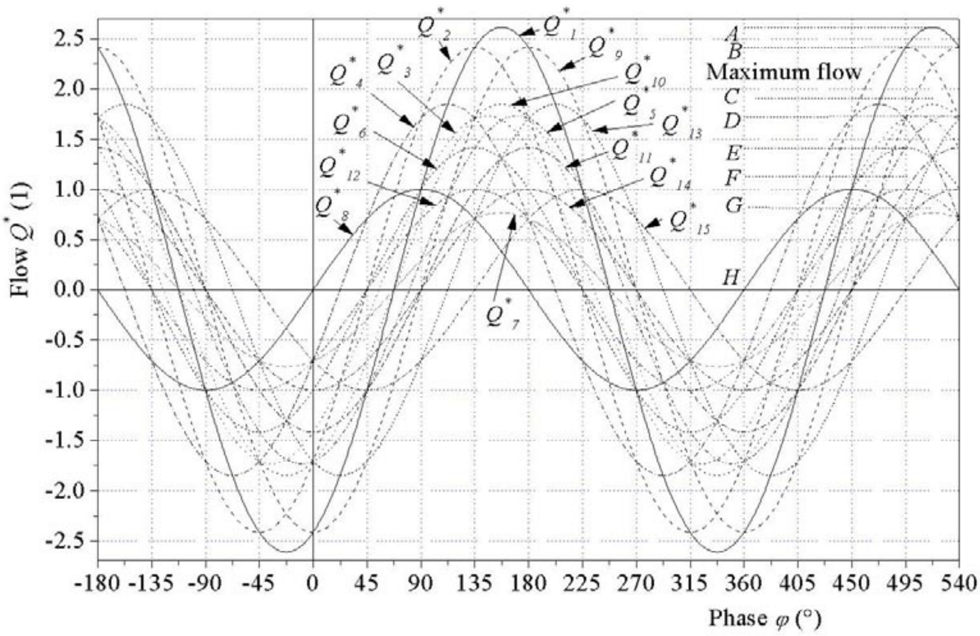

Figure 14. Different relative flow amplitude combinations achieved by omitting some elements having z = 4 pistons in a phase; Q_j^*– relative flow of the i element

Table 5. Combinations available for z = 5 pistons in the phase

No.	Type	Pistons					Amplitude A_Q	Phase shift value β	Angle at maximum ϕ_m
		1	2	3	4	5			
1	N	1	1	1	1	1	3.236068	2·π/5 = 72°	9·π/10 = 162°
2	M	1	1	1	1	0		3·π/10 = 54°	4·π/5 = 144°
3	L	1	1	1	0	1			
4	J	1	1	1	0	0		π/5 = 36°	6·π/5 = 126°
5	K	1	1	0	1	1			
6	H	1	1	0	1	0			
7	G	1	1	0	0	1			
8	C	1	1	0	0	0		π/10 = 18°	3·π/5 = 108°
9	L	1	0	1	1	1			
10	H	1	0	1	1	0			
11	I	1	0	1	0	1		2·π/5 = 72°	9·π/10 = 162°
12	D	1	0	1	0	0		π/5 = 36°	6·π/5 = 126°
13	G	1	0	0	1	1			
14	E	1	0	0	1	0		3·π/10 = 54°	4·π/5 = 144°
15	F	1	0	0	0	1		2·π/5 = 72°	9·π/10 = 162°
16	B	1	0	0	0	0	1.0	0·π = 0°	π/2 = 90°
17	M	0	1	1	1	1		π/2 = 90°	π = 180°
18	J	0	1	1	1	0		2·π/5 = 72°	9·π/10 = 162°
19	H	0	1	1	0	1			
20	C	0	1	1	0	0		3·π/10 = 54°	4·π/5 = 144°
21	H	0	1	0	1	1			
22	D	0	1	0	1	0		2·π/5 = 72°	9·π/10 = 162°
23	E	0	1	0	0	1		π/2 = 90°	π = 180°
24	B	0	1	0	0	0	1.0	π/5 = 36°	6·π/5 = 126°
25	J	0	0	1	1	1		3·π/5 = 108°	11·π/10 = 198°
26	C	0	0	1	1	0		π/2 = 90°	π = 180°
27	D	0	0	1	0	1		3·π/5 = 108°	11·π/10 = 198°
28	B	0	0	1	0	0	1.0	2·π/5 = 72°	9·π/10 = 162°
29	C	0	0	0	1	1		7·π/10 = 126°	6·π/5 = 216°
30	B	0	0	0	1	0	1.0	3·π/5 = 108°	11·π/10 = 198°
31	B	0	0	0	0	1	1.0	4·π/5 = 144°	13·π/10 = 234°
32	A	0	0	0	0	0	0.0	0.0°	0.0°

β, ϕ_m – in relation to the 1st piston

As evident (Figure 15), 4 pistons in the phase can already form eight basic combinations. Thus, the application possibilities of the converter in hand (of uniform size) can get extended since a wider range of applicable amplitudes is obtained. Combinations 1*A*, 2*B*, 4*C*, 3*D*, 6*E*, 8*F*, 7*G* and 16*H* are arranged in a sequence respecting the phase shift, starting with the lowest amplitude.

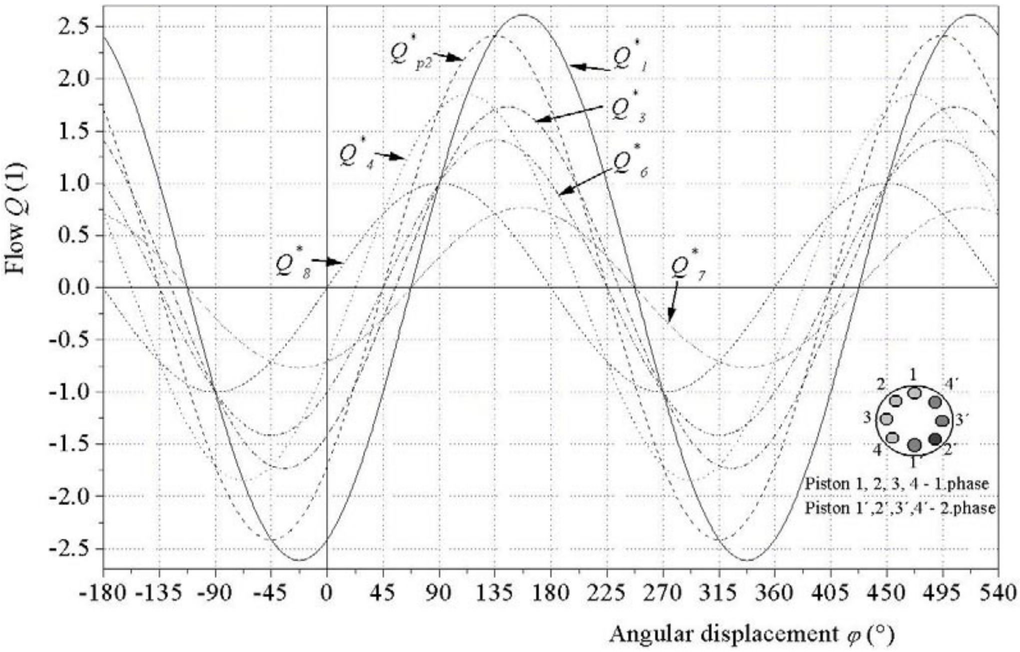

Figure 15. Basic amplitude flow combinations achieved by omitting some elements having z = 4 pistons in the phase; Q^*_j – relative flow of the *i* element

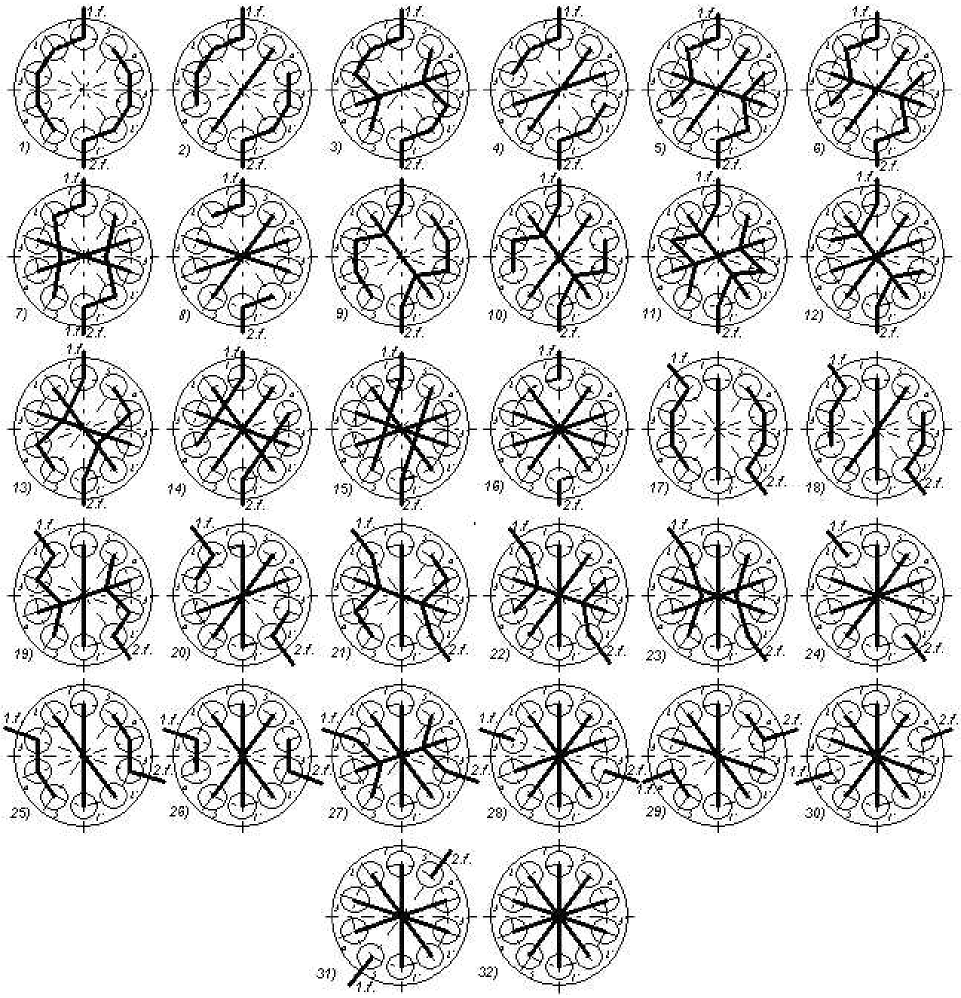

Figure 16. Various combinations of flow amplitude achieved by omitting some elements while having *z* = 5 pistons in the phase; 1–5 – phase 1 elements, 1´–5´ – phase 2 elements

Let there be five elements (pistons) in the phase. It is possible to make thirty-two combinations if connecting opposite elements in phases with those being part of the phase. Table 5 shows some numeric values and Figure 16 shows individual combination types. The combinations given are assigned fourteen basic combinations of the resulting amplitudes *A* to *N*. The basic combinations extend the application possibilities of the five-piston converter in hand by forming fourteen differently sized amplitudes.

There may be more to the basic combinations, but they have different phase shifts β. It is advisable to opt for a combination with a smaller phase shift value β. When switching combinations, it is advisable to select such a sequence in which the neighboring combinations are of smaller phase shift value.

There is one combination of *A* type (amplitude is $A_Q = 0$). Its purpose is to prevent the flow to arise in the converter phases. Opposite elements are all interconnected. This combination is advisable for a pump having a stationary motor.

There are five combinations of *B* type (No. 16, 24, 28, 30 and 31) with $A_Q = 1$ amplitude per unit. For combination No. 16 makes zero phase shift value ($\beta = 0$), it is advisable to be matched with the combination No. 32 to respect the combination sequence.

There are four combinations of *C* type (No. 8, 20, 26 and 29) having a higher amplitude than *A* type. The slightest phase shift value $\beta = 18°$ is attributed to combination No. 8, therefore it is the next one in the sequence of combinations.

There are three combinations of *D* type (No. 12, 22 and 27). The slightest phase shift value $\beta = 36°$ is attributed to combination No. 12. It is therefore placed next in the sequence of combinations.

Values that were not given are not registered.

This procedure can be applied when selecting basic combinations of basic types.

CONCLUSION

The paper presents a method to create geometric displacement volume of the piston converter phase with the fluid alternating flow. It is basically achieved by adding or omitting elements in the phase. Thus, various flow amplitude combinations may be reached. The resulting flow behaviors show that the phase shift β value differs if having a different number of elements in the phase *z*, $z = 1$ excluding. This is supported by an analysis in which the additional elements in the phase were gradually arranged in the left direction from the first element by α angle. The relations and behavior types are true supposed that the cross-sections of all elements (pistons) in the phase are identical and arranged alongside the pitch circle of the cylinder block in a regular manner.

The method presented in the paper illustrates various possibilities of combining pistons in the phase which is instrumental for the manufacturers to choose and apply different options for the two-phase converters. In addition, it makes the production of two-phase converters more efficient. The method can be applied to produce converters in various industries such as cutter bar drive (Krchnár & Stračár 2000; Pavlok 2004), shaking sieves, fatigue testing machines, vibrating hammers etc. (Turza *et al.* 2005).

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Abstrakt

Turza J., Tkáč Z., Gullerová M. (2007): **Geometrický objem a prietok fáze prevodníka dvojfázového hydraulického mechanizmu.** Res. Agr. Eng., **53**: 54–66.

Obsah príspevku je zameraný na problematiku možnosti nahradenia hydrostatických pohonov poľnohospodárskych strojov s jednosmerným prietokom pracovnej kvapaliny, hydrostatickými pohonmi so striedavým prietokom, ktoré umožňujú výhodnejšie riešiť systém pohonu s výstupným striedavým pohybom. Práca sa zaoberá metódou vytvárania geometrického objemu fáze piestového prevodníka so striedavým prietokom. Koná sa to pomocou rôzneho počtu prvkov vo fáze, alebo vynechaním prvkov vo fáze. Znižuje sa tým počet typov vyrábaných prevodníkov.

Kľúčové slová: geometrický objem; striedavý prietok; dvojfázový mechanizmus

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