PROGRESS IN THE APPLICATION OF AXIAL COMBINED TOOLS

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ABSTRACT

Conditions of application of combined axial tools are considered to ensure maximum saving of machining time for parts. Their advantages compared to conventional tools are reflected – in addition to reducing the main technological time and auxiliary time, it is also a reduction in the number of technological equipment, increasing alignment and accuracy of the location of the individual stages of the machined holes. New, more advanced tool designs are shown, which are created taking into account the appearance of progressive materials and wear-resistant coatings.

Keywords: transport engineering, metalworking, drill, countersink, machine time, axial tool, combined tool.

Background. *To combine operations or transitions when processing stepped and smooth holes, all kinds of combined tools are used. The most common are step drills and step countersinks, drill-countersinks, drill-countersink-drills, drill-countersinks-countersinks. We can also include here drill-taps.*

These tools are used in turning, turret, drilling, aggregate machines, as well as automatic lathes and semi-automatic machines.

Combined tools in most cases have a target purpose and are intended only for processing of certain parts. They find their place mainly in mass production.

The most widely used combined axial tools have been obtained in the automotive industry, but are also used in other areas of engineering.

Holes that can be machined with axial combined tools account for up to 75 % of all machined surfaces.

Axial combined tools in comparison with conventional ones, as a rule, receive the following advantages [1]:

1. The main technological time is reduced, as well as the auxiliary time associated with the supply and removal of the tool, its replacement and adjustment, and, accordingly, both the technological and cyclic productivity are increased.

2. The quantity of technological equipment is reduced, due to which the energy consumption, production areas, the number of basic and auxiliary workers are reduced, the reliability of automatic lines is increased, and the cost of production also decreases.

3. The alignment and accuracy of the individual stages of the machined holes increases.

Objective. *The objective of the authors is to consider progress in the application of axial combined tools.*

Methods. *The authors use general scientific and engineering methods, comparative analysis, mathematical apparatus, evaluation approach.*

Results.

Let's consider some cases of application of axial combined tools.

1. A through smooth hole (Pic. 1a) in a solid material can be processed with either one-dimensional or combined tools.

When processing with one-dimensional tools – a drill (Pic. 1b) and a countersink (Pic. 1c), the main time for each of these tools is determined by the formula:

$$\mathrm{Tm} = \frac{L + \mathrm{ui} + \Delta\mathrm{i}}{n \cdot S},$$

where L – length of the hole, mm; ui – insertion of a tool, mm; Δi – tool overrun, mm; n – number of revolutions, rpm; S – feed, mm/rev.

Total main time Tm_{Σ} will be: $Tm_{\Sigma 1} = Tm_{dr} + Tmc$, where Tmdr – axial time when processing is performed with a drill, Tmc – axial time when processing is performed by a countersink, min.

When the same hole is processed (Pic. 2a) with a combined tool type «drill-countersink» in a sequential manner first a hole is drilled for its entire length (Pic. 2b), and then, after the drill is out, a countersink is made (Pic. 2c).

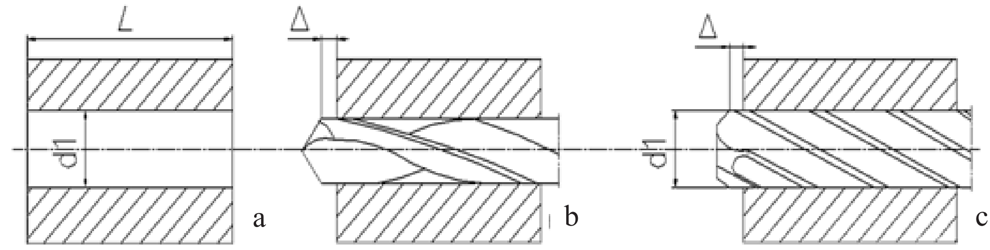
Obviously, even in this case, $T_{\Sigma 2} = Tm_{dr} + Tm_c = Tm_{\Sigma 1}$, i.e. there is no gain in the main time compared to processing with one-dimensional tools.

The same hole (Pic. 3a) can be processed with a combined tool type «drill-countersink» in a combined scheme. Then, first the drill is turned on (Pic. 3b), and then after the deepening by the length ℓ4 the countersinking begins.

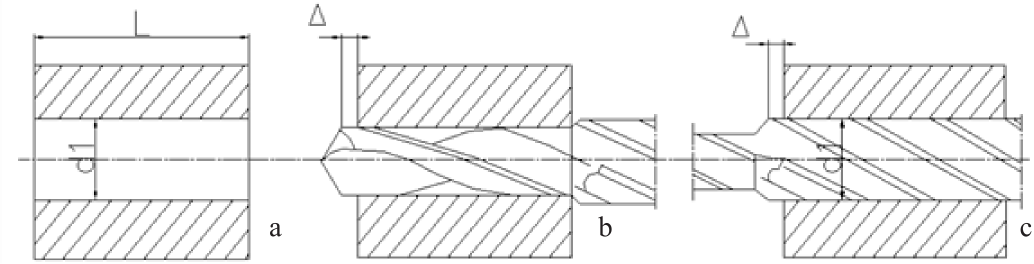
Thus, in the section l4 the drill operates alone, i.e. there is a sequential scheme, and in the section L–ℓ4, cutting takes place in parallel with two tools at the same time.

The working time of the drill in the sequential scheme is equal to:

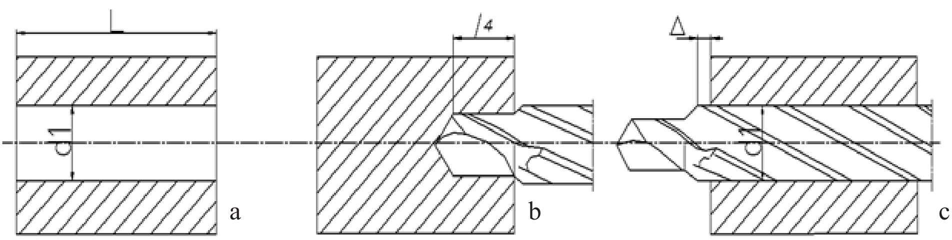
$$\mathrm{Tmdr1} = \frac{\ell 4 + Udr}{n \cdot S}$$ *, where U_{dr} – drill insertion, mm.*



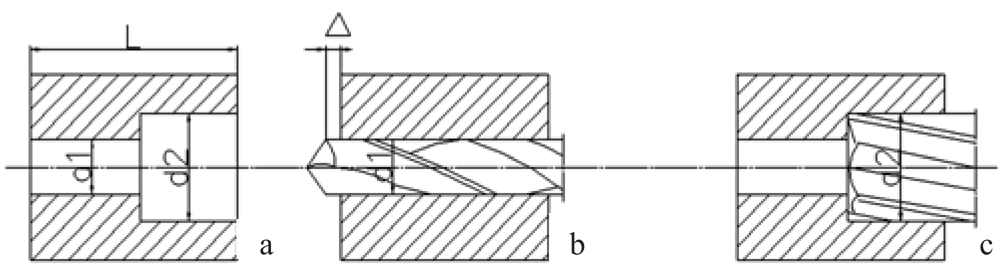
Pic. 1. Processing of a smooth hole with one-dimensional tools.



Pic. 2. Processing of a smooth hole with a combined tool in a sequential pattern.



Pic. 3. Processing a smooth hole with a combined tool in a combined scheme.



Pic. 4. Processing of a two-step hole with one-dimensional tools.

The working time of the drill according to the parallel scheme $\mathrm{Tmdr2} = \dfrac{L-(\ell 4+\Delta dr)}{n{\cdot}S}$*, where* Δdr *– overrun of the drill in mm.*

Tmdr2 is not included in the calculation of the total main time, since drilling in the section L–ℓ4 is fully aligned with the countersink.

The working time of the countersink

$$T_{mcs} = \frac{L+U_{в}+\Delta_{cs}}{n{\cdot}S}$$

where Ucs is the countersink insertion, Δcs *is the countersink overrun, mm.*

The total main time will be

$$Tm_{\Sigma cs} = Tm_{cs} + Tmdr1 = \frac{L+U_{cs}+\Delta_{cs}}{n{\cdot}S} + \frac{\ell 4 - Udr}{n{\cdot}S}$$

The difference in main time when processing with one-dimensional ($Tm_{\Sigma 1}$*) and combined (*$Tm_{\Sigma cs}$*) tools will be:*

$$T_1 = T_{m\Sigma 1} - T_{m\Sigma cs} =$$

$$\left(\begin{array}{c}\dfrac{L+Udr+\Delta \mathrm{dr}}{n{\cdot}S}+\\ \dfrac{L+Ucs+\Delta \mathrm{cs}}{n{\cdot}S}\end{array}\right) - \left(\begin{array}{c}\dfrac{L+Ucs+\Delta \mathrm{cs}}{n{\cdot}S}+\\ \dfrac{\ell 4+Udr}{n{\cdot}S}\end{array}\right) =$$

$$= \frac{L+Ucs+\Delta \mathrm{cs}}{n{\cdot}S} - \frac{\ell 4+Udr}{n{\cdot}S},$$

i.e. the smaller is the length of section ℓ4, on which the drill works in a sequential pattern, the greater is the gain in the main time when working with combined tools.

The minimum length of section ℓ4 is determined by the minimum length of the drill, which must be at least 1,25d, where d is the diameter of the drill, mm.

2. A two-step hole (Pic. 4a) in a solid material can be processed with either one-dimensional tools or a combined «drill-countersink» type.

In the first variant, the hole is first drilled (Pic. 4b), and then processed by a countersink (Pic. 4c).

The main time when drilling is determined by the formula:

$$\mathrm{Tmdr} = \frac{L+Udr+\Delta \mathrm{dr}}{n{\cdot}S},$$

where Udr – drill insertion, Δdr *– drill overrun, mm.*

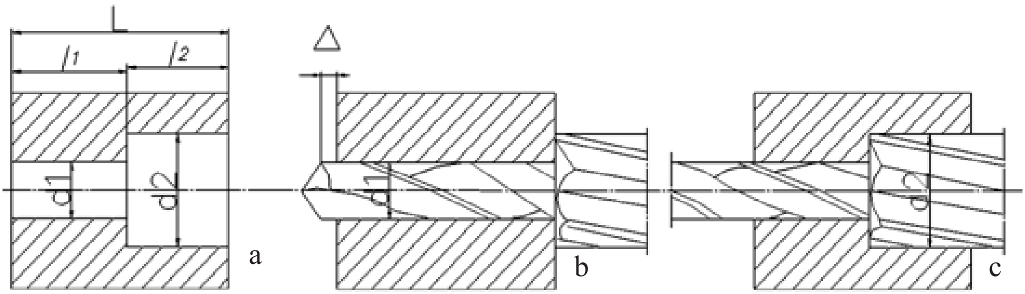
When processing with the countersink

$$\mathrm{Tmcs} = \frac{\ell 2}{n{\cdot}S}\ \textit{min.}$$

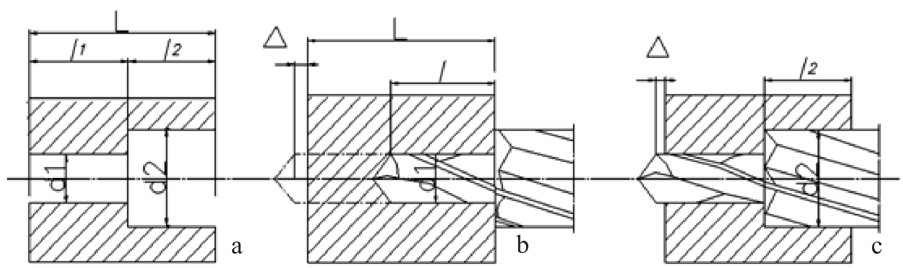
The total main time will be:

$$Tm_{\Sigma 4} = Tm_{dr} + T_{mcs} = \frac{L+Udr+\Delta \mathrm{dr}}{n{\cdot}S} + \frac{\ell 2}{n{\cdot}S}\,\textit{min.}$$

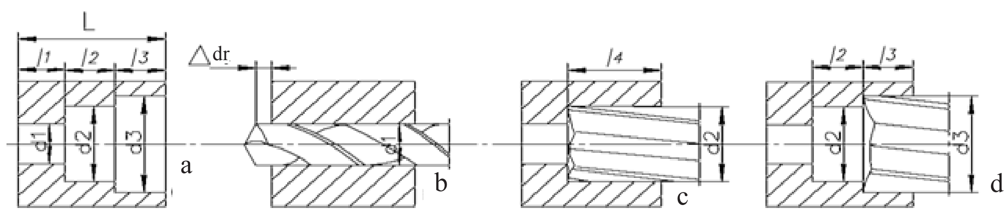
In the second variant, the processing of the step hole (Pic. 5a) is performed by a combined tool of the «drill-countersink» type in a sequential pattern, i.e.



Pic. 5. Processing of a two-staep hole with a combined tool in a sequential pattern.



Pic. 6. Processing of a two-stage hole with a combined tool according to a combined scheme.



Pic. 7. Processing of a three-stage hole with one-dimensional tools.

first, a drill is working on the length (L + Δdr + Udr) (Pic.5b), and after drilling, the hole is bored in the section ℓ2 (Pic. 5c).

The main time when the drill is working is:

$$\mathrm{Tmdr} = \frac{L + Udr + \Delta \mathrm{dr}}{n \cdot S},$$

where L – length of a hole, Δdr – drill overrun, Udr – drill insertion, mm.

The main time when the countersink is working is

$$\mathrm{Tmcs} = \frac{\ell 2}{n \cdot S},$$

where ℓ2 – length of a second step of the hole, mm.

The total main time $Tm_{\Sigma 5}$ will be $Tm_{\Sigma 5}$ = Tmdr + Tmcs = Tm_4,

i.e. there is no time gain compared to processing with one-dimensional tools.

3. The same hole (Pic. 6a) can be made by a combined tool of the «drill-countersink» type, working in a combined scheme. In this case the drill in a sequential pattern (Pic. 6b) is working over a length ℓ = (L + Δdr) + ℓ2, wherein Δdr – drill overrun, mm.

Then, together with the drill, the countersink starts to work, performing the countersinking of the section ℓ2, i.e. cutting in parallel.

The main time Tdr1 when the drill is working on the section ℓ will be: $\mathrm{Tdr1} = \dfrac{\ell + Udr}{n \cdot S}$,

where Udr – drill insertion, mm.

The main time Tmdr2 when the drill is working on the section ℓ1:

$$\mathrm{Tmdr2} = \frac{(L + \Delta dr) - \ell 2}{n \cdot S},$$

where Δdr – drill overrun, mm.

The main time of the countersink work on the section is ℓ2: $\mathrm{Tmcs} = \dfrac{\ell 2}{n \cdot S}$.

The total main time:

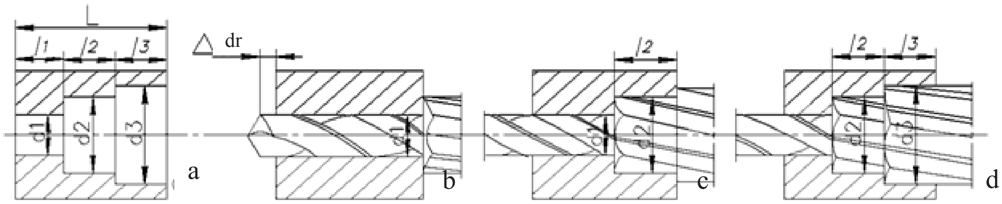
$$Tm_{\Sigma 6} = Tm_{dr1} + Tmcs = \frac{\ell + y}{n \cdot S} + \frac{\ell 2}{n \cdot S}.$$

The main time to of drill work on the section ℓ1 is not included in the calculation of the total main time, since it is completely in the area ℓ aligned with work of the countersink on the section ℓ2. Here the drill and the countersink operate simultaneously.

The difference in main time between processing with one-dimensional $Tm_{\Sigma 4}$ and combined $Tm_{\Sigma 6}$ tools will be:

$$T_{m2} = Tm_{\Sigma 4} - Tm_{\Sigma 6} = \left[\frac{L + Udr + \Delta dr}{n \cdot S} + \frac{\ell 2}{n \cdot S}\right] - \left[\frac{\ell + y}{n \cdot S} + \frac{\ell 2}{n \cdot S}\right] = \frac{L + Udr + \Delta dr}{n \cdot S} - \frac{\ell + y}{n \cdot S}, \text{ min.}$$

Hence, the smaller the length of the section ℓ on which the drill operates in a sequential pattern (i.e. the shorter is the drill), the greater is the gain T2 in



Pic. 8. Processing of a three-stage hole with a combined tool in a sequential pattern.

the main time between the processing with one-dimensional and combined tools. The minimum length of the drill and in this case should not be less than 1,25 d, where d is the diameter of the drill.

In addition, when processing with a combined scheme, the longer is the hole length, the greater is the gain in time compared to the processing of the same hole by one-dimensional tools.

4. Now take the three-stage hole (Pic. 7a). As in the previous two cases, one-dimensional and combined tools can be used for processing here.

In the version with one-dimensional tools, the hole is first drilled with a drill (Pic. 7b), and then it is processed by the countersink d2 (Pic. 7c) and the countersink d3 (Pic. 7d) for a length of ℓ3.

The main time when processing with a drill:

$\mathrm{Tmdr} = \frac{L+Udr+\Delta dr}{n{\cdot}S}$ *, where Udr – drill insertion, Δdr – drill overrun, mm.*

The main time in case of operations with the countersink d2:

$\mathrm{Tmcs1} = \frac{\ell 4}{n{\cdot}S}$ *; with the countersink d3:* $\mathrm{Tmdr2} = \frac{\ell 3}{n{\cdot}S}$.

The total main time will be:

$$Tm_{\sum_7} = Tmdr + Tmcs1 + Tmcs2 = \frac{L+Udr+\Delta dr}{n{\cdot}S} + \frac{\ell 4}{n{\cdot}S} + \frac{\ell 3}{n{\cdot}S}, \text{ min.}$$

5. In case of processing of a similar hole (Pic. 8a) with a combined tool in a sequential pattern, the hole is first drilled to the full length with a drill d1 (Pic. 8b), then it is processed by the countersink d2 at a length of ℓ2 (Pic. 8b) and then with the countersink d2 and d3 (Pic. 8d).

The main working time of the drill:

$\mathrm{Tmdr} = \frac{L+Udr+\Delta dr}{n{\cdot}S}$ *, where Udr – drill insertion in mm.*

The main time of the first countersink (d2) is:

$$\mathrm{Tmcs1} = \frac{\ell 2}{n{\cdot}S}.$$

The main time of the second countersink (d3) is:

$$\mathrm{Tmcs2} = \frac{\ell 3}{n{\cdot}S}.$$

In this example, for a length L, the drill and the first countersink for length ℓ2 operate in a sequential pattern simultaneously with the second countersink processing the diameter d3, so the total main processing time is:

$$Tm_{\sum_8} = Tmdr + Tmcs1 = \frac{L+Udr+\Delta dr}{n{\cdot}S} + \frac{\ell 2}{n{\cdot}S}, \text{ min.}$$

The difference in the main time between processing with one-dimensional tools and a combined tool here is expressed by the formula:

$$Tm3 = Tm_{\sum_7} - Tm_{\sum_8} = \left[\frac{L+Udr+\Delta dr}{n\cdot S} + \frac{l4}{n\cdot S} + \frac{l3}{n\cdot S}\right] - \left[\frac{L+Udr+\Delta dr}{n\cdot S} + \frac{l2}{n\cdot S}\right] = \left[\frac{l4}{n\cdot S} + \frac{l3}{n\cdot S}\right] - \frac{l2}{n\cdot S}.$$

Hence it follows that the longer is the length of the second stage of the hole, the smaller is the difference between the time of hole processing with one-dimensional and combined tools, since the second stage works in a sequential pattern.

6. In conclusion, a variant of processing of the same three-stage hole (Pic. 9a) with a combined toll «drill-countersink-countersink» according to the combined scheme.

In this case, first the hole d1 is drilled to the length ℓ (Pic. 9b), then the holes d1 to the length ℓ + ℓ2 and the countersinking of the hole d2 to the length ℓ2, then the simultaneous drilling of the hole d1 to the length ℓ2 + ℓ3 + Δdr, countersinking of the second stage of the hole d2 by the length ℓ2 + ℓ3 and the third stage of the hole d3 by the length ℓ3.

The main time when the drill is working:

$\mathrm{Tmdr} = \frac{L+U}{n{\cdot}S}$ *, where l = (L + Δdr) –(ℓ2 + ℓ3), u – drill insertion, mm.*

The main time when the first countersink is working: $\mathrm{Tmcs1} = \frac{\ell 2+\ell 3}{n{\cdot}S}$.

The main time when the second countersink is working: $\mathrm{Tmcs2} = \frac{\ell 3}{n{\cdot}S}$.

Due to the fact that the countersinking of both diameters d2 and d3 is completely time-synchronized with the drilling of diameter d1, the calculation of the total main time reduces to the formula:

$$\mathrm{Tm}_{\sum_9} = \mathrm{Tmdr} = \frac{L+Udr+\Delta \mathrm{dr}}{n{\cdot}S},$$

where Udr – drill insertion, Δdr – drill overrun, mm.

The difference in main time with processing with one-dimensional tools will be:

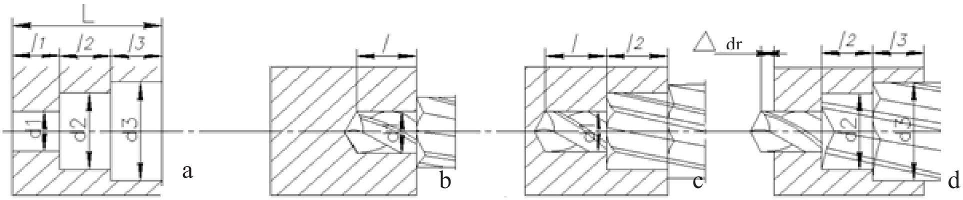
$$Tm_4 = Tm_{\Sigma 7} - Tm_{\Sigma 9} = \frac{L+Udr+\Delta \mathrm{dr}}{n{\cdot}S} + \frac{\ell 4}{n{\cdot}S} + \frac{\ell 3}{n{\cdot}S} - \frac{L+Udr+\Delta \mathrm{dr}}{n{\cdot}S} = \frac{\ell 4}{n{\cdot}S} + \frac{\ell 3}{n{\cdot}S},$$

where L – length of the hole, Δdr – drill overrun, Udr – drill insertion, mm. In this case ℓ3 and ℓ4 – length of stages of the hole (ℓ4 = ℓ2 + ℓ3).

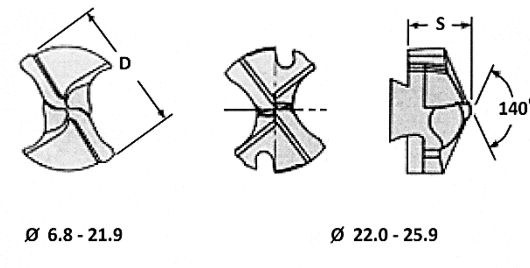
Hence the conclusion:

1. When working with a combined tool in a combined scheme, the more is the number of stages of the hole and the greater is length, the greater is the gain in the main time compared to the processing with one-dimensional tools.

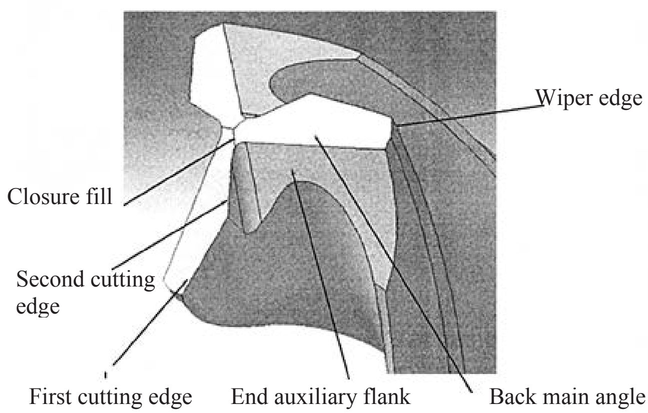
2. The smaller is the length of the drill, the earlier the process of combined processing will begin and



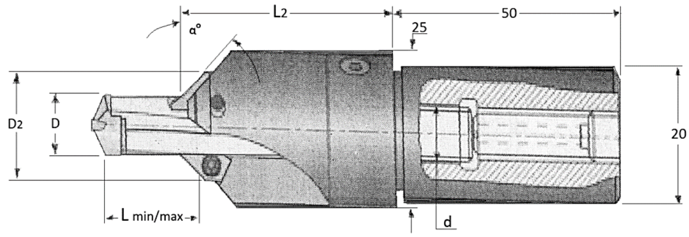
Pic. 9. Processing of a three-stage hole with a combined tool according to a combined scheme.



Pic. 10. Replaceable drilling heads.



Pic. 11. Three-edge drill.



Pic. 12. Combined drill-countersink with interchangeable non-re-insertable plates.

there will be more gain in the main time compared with the processing with one-dimensional tools.

Of course, experts know that combined axial tools have a number of drawbacks. For example, a high degree of concentration of cutting edges ensures cutting of a larger mass of metal, but increases the design of forces and the cutting temperature on the common tool body, which worsens the working conditions.

The increase in the volume of the metal to be cut makes it difficult to remove it through the flute grooves, and this can lead to chip packing. The chips are also packaged in the presence of ledges on the surfaces of the chip flutes, which is the case with a large difference between the diameters of the tool steps. It also leads to an increase in frictional forces, an increase in temperature in the cutting zone. The growth of frictional forces creates the prerequisites for breaking and roughness of the hole surface, and sometimes for tool breakage.

Similar shortcomings are inherent in one-dimensional tools, but they are manifested to a greater degree in combined ones, and at the same time sometimes limit their application. However, the situation is changing, the shortcomings can be *reduced by innovative means. In recent years, significant progress has been made in the tool industry, which is explained both by the use of new tool materials and wear-resistant coatings, and by the creation of new tool designs [14].*

Due to this progress the opportunity has appeared:

1. When designing axial combined tools with a drill in their composition, use replaceable drilling heads (Pic. 10), with which it is possible to significantly extend the tool life. These heads are available with diameters from 8 to 25 mm and allow up to three rewetches.

2. Produce axial combined tools with internal channels for the supply of coolant. Internal cooling contributes to an intensive heat sink and thus removes many previous problems.

3. In tools of drill-countersink type, the number of grooves in the drill and countersink must be the same or as multiple as possible. Therefore, in tools where there are three-edge countersink, a three-edge drill is now possible (Pic. 11), followed by a smooth transition of its grooves into wider grooves of the countersink. When using four-edge countersinks, two-edge drills should be used with a smooth transition of the grooves into coincident but wider grooves of the countersink.

4. It is known that when processing by cutting a significant part of the heat flows into the body of the tool. Therefore, it was decided to make the tool bodies more massive from steels that possess not only the specified mechanical characteristics, but also good thermal conductivity.

5. If there is a significant difference in the diameters of the individual stages, it is recommended that chip removal from the first stage is carried out through internal chip channels (holes) made in an adjacent step.

6. The working conditions of the combined drill-countersink tool are facilitated by exchangeable non-re-tachable plates with mechanical fastening and wear-resistant coating (Pic. 12).

As for another position that needs to be strengthened – increased breakdown of the holes, it is mainly related to the accuracy of the tool and the class of the machine tool. For example, the effects of asymmetric sharpening of a drill and the importance of pre-centering with a centering drill are known. After deepening the drill-countersink at 1,25–1,5 d, it acts as a guide pin and helps reduce the breaking of the hole.

Of course, all these changes must be consistent with the configuration of the hole being processed, the material of the part, the requirements for hole accuracy and the quality of the surface.

Conclusions.

1. The emergence of modern instrumental materials and wear-resistant coatings in the designs of combined instruments can significantly expand the scope of their application.

2. The use of new versions of one-dimensional tools in the designs of combined tools eliminates many inherent disadvantages.

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