5.0 Busbar Profiles
David Chapman

5.1 Introduction

Busbar profiles are very often used in distribution panels and switchboards where they have some distinct advantages. The design considerations for this application are significantly different from the relatively long vertical and horizontal busbars discussed previously. For example, the bars are semi-enclosed in cabinets, so it is the air flow through the cabinet which determines the cooling available. Moreover, these cabinets contain a substantial number of devices such as circuit breakers, which also generate heat and rely on the busbar system to remove it. Space constraints, mounting considerations and ease of assembly also favour the use of profiles.

Profiles are more difficult and costly to manufacture than flat bars due to technical constraints, including:

- Complex design
- More elaborate machine set-up
- More delicate production process
- More complicated packaging.

These constraints are now mostly under control and currently several fabricators produce hundreds, or even thousands, of different shapes for electrical applications.

Many electrical parts, which are often cut from sheet, can be economically produced by slicing a profiled bar.

5.2 Reasons for Using Profiles

Profiles can be used to reduce the weight of copper conductors in an existing product. For an existing oversized conductor, the design flexibility available to define the shape of drawn copper profiles allows the engineer to design a profile smaller without affecting those surfaces which are constrained by the presence of existing support points, or contact interfaces.

5.2.1 Skin Effect Reduction

Skin effect losses are perhaps less important in switchgear, where the lengths are relatively short, than it is in long distribution busbars. However, taking proper account of skin effect often allows the amount of material to be significantly reduced.

5.2.2 Weight and Cost Saving

As discussed elsewhere, the apparent impedance of thick section conductors is increased due to skin effect, meaning that the current density in the centre is much lower than that at the surface. In a simple rectangular bar, there are areas of the cross-section in which the current density is comparatively low; using a correctly designed profile allows for a near homogeneous current density across the section that allows material to be removed from these areas, saving material, cost and weight.
5.2.3 Integrated Fixings and Mountings

Profiles can be designed to allow fast, hole-free assembly and jointing, which can significantly reduce the time required to assemble bars in a cabinet, improving consistency and quality.

5.2.4 Retention of Intellectual Integrity

Using bespoke profiles allows OEMs to ensure that cabinets assembled by sub-contractors conform to their specifications, avoiding the risk of substitution of inferior materials and assembly processes.

5.3 Economics of Profiles

The material savings generated by replacing a standard conductor by a profile of even a slightly smaller cross-section can easily offset the higher processing costs. At current refined copper prices, by far the largest contributor to the cost of a drawn copper profile is the cost of the copper material itself.

Using profiles also gives the opportunity to capture other savings:

- Hole-free joints and mountings yielding to lower assembly time and reduced complexity
- Lower scrap generated at the point of use (drilling and cutting not required)
- Flexible sourcing (optimum profiled conductor or standard product with identical supports and mounting points)
- Optimum material usage for the specific application
- Easier re-engineering and conductor optimisation on an existing product.

5.4 Practical Profiles

5.4.1 Manufacturing Process

Profiles are manufactured by extrusion, followed by one or more stages of drawing. The copper is extruded, either continuously or discontinuously through a die along a horizontal bench which supports the material. It is either cut into lengths or coiled for further processing.

The profile is then drawn through one or more dies, the last of which defines the final size and shape. Drawing is a cold working process so the drawn material is significantly hardened. The choice of extruded size and the number of drawing stages and their reductions determines the final hardness of the material; usually, the aim is to achieve the final size and shape without excessive hardening.

For profiles it is important that the size reduction during drawing is uniform – in other words that, while the size is reduced, the shape remains similar – to prevent differential hardening of the bar. For example, inappropriate tool and process design can, among other things, lead to problems with twisting, more so for asymmetric profiles.

5.4.1.1 EN 13605

EN 13605 is the standard that specifies the composition, properties and dimensional tolerances for copper profiles and profiled wire for electrical purposes which would fit within a circumscribing circle with a maximum diameter of 180 mm. The standard also specifies how ordering information should be structured between supplier and customer.
Figure 50 – A non-typical profile indicating the dimensions used in the standard

It is not intended here to describe the requirements of the standard in great detail but some aspects which are particularly relevant to profiles deserve mention.

Figure 50 shows a non-typical profile and the dimensions used to specify tolerances. Note that the standard is limited to those profiles that have a cross-section that can be contained within a circle of 180 mm diameter. A large majority of profiles are smaller than this, typically limited to 165 mm x 30 mm or 65 mm square with a weight of 30 kg/m. Some manufacturers are capable of manufacturing much larger profiles with maximum dimensions and the appropriate tolerances must be agreed between customer and supplier. Maximum dimensions for two processes are given in Table 17.

The tolerances on the major dimensions, \( b \) and \( h \) in Figure 50, are categorised by value and defined in six groups according to:

- The diameter of the circumscribing circle diameter in three groups, up to 50 mm, between 50 mm and 120 mm and between 120 mm and 180 mm
- The ratio of the maximum dimension (\( b \) or \( h \)) to the minimum thickness (\( s \)) into two sets:
  - \( b_{\text{max}} < 20 \ s_{\text{min}} \) or \( h_{\text{max}} < 20 \ s_{\text{min}} \)
  - \( b_{\text{max}} \geq 20 \ s_{\text{min}} \) or \( h_{\text{max}} \geq 20 \ s_{\text{min}} \)

Tables 14, 15 and 16 list the tolerances.
Table 14 – Tolerances for Dimensions \( b \) and \( h \) for \( b_{\text{max}} \) or \( h_{\text{max}} \) < 20:1

<table>
<thead>
<tr>
<th>Nominal Dimensions ( b ) and ( h ) (mm)</th>
<th>Tolerances for Dimensions ( b ) and ( h ) within a Circumscribing Circle</th>
</tr>
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<tbody>
<tr>
<td>Over</td>
<td>Up to and including</td>
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<td>80</td>
<td>120</td>
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<td>120</td>
<td>180</td>
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</tbody>
</table>

Table 15 – Tolerances for Dimensions \( b \) and \( h \) for \( b_{\text{max}} \) or \( h_{\text{max}} \) ≥ 20:1

<table>
<thead>
<tr>
<th>Nominal Dimensions ( b ) and ( h ) (mm)</th>
<th>Tolerances for Dimensions ( b ) and ( h ) within a Circumscribing Circle</th>
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</thead>
<tbody>
<tr>
<td>Over</td>
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<td>120</td>
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The tolerances on thickness \( s \) in Figure 50 are specified for profiles with a circumscribing circle of 50 mm and below and one of greater than 50 mm.

Table 16 – Thickness Tolerances

<table>
<thead>
<tr>
<th>Nominal Thickness (mm)</th>
<th>Thickness Tolerance within a Circumscribing Circle</th>
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<tbody>
<tr>
<td>Over</td>
<td>Up to and including</td>
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<td>30</td>
<td>50</td>
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</tbody>
</table>

5.4.1.1 Straightness, Flatness and Twist

Profiled sections are often used as pre-manufactured components for switchgear assemblies where space is limited and clearance distances are important, so it is essential that the sections fit correctly. Since profiles are much stiffer than flat bars, they cannot easily be pulled into alignment during assembly, so it is essential that they are straight, flat and free from twisting. Measurement of straightness, flatness and twist is made with the test piece lying on a flat reference surface.

In Figure 51, \( h \) represents the deviation from straight over length \( l \); \( h_1 \) must be less than 3 mm per metre length \( l \) up to 3 m while \( h_2 \) must be less than 1.2 mm for any 400 mm length. It should be noted that, for special requirements, a straightness of less than 1 mm in a 1000 mm length can be achieved.
Figure 51 – Measurement of straightness

Figure 52 illustrates the measurement of flatness.

Figure 52 – Measurement of flatness

Figure 53 illustrates the method for measuring twist. The twist tolerance is defined by

\[ f = \frac{v}{b} \]

where:
- \( v \) is the displacement from the reference plane
- \( b \) is the width of the test piece
- \( f \) is a coefficient, the tolerance limit.

Again, the limiting value of \( f \) is grouped according to the diameter of the circumscribing circle (\( \geq 15 \) and \( \leq 50; >50 \) and \( \leq 120; >120 \) and \( \leq 180 \)) as a maximum value per metre of length and as a maximum for any length over 2 m.
### Table 17 – Coefficient for Twist Tolerance

<table>
<thead>
<tr>
<th>Diameter of Circumscribing Circle (mm)</th>
<th>Coefficient $f$ for Twist Tolerance $\nu$</th>
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<tbody>
<tr>
<td><strong>Over</strong></td>
<td><strong>Up to and including</strong></td>
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<td>15&lt;sup&gt;a&lt;/sup&gt;</td>
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<td>50</td>
<td>120</td>
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<td>120</td>
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<sup>a</sup> including 15

### 5.4.2 Design for Manufacturing

As might be expected, some profile designs are easier to manufacture than others; taking account of the capabilities of the manufacturing process during the design phase may help to reduce the cost and result in more consistent quality of the final product.

The overall size of the profile must lie within the capacity of the available plant. Manufacturers quote different limits depending on the process used, so advice should always be sought from potential manufacturers.

<table>
<thead>
<tr>
<th>Table 18 – Maximum Sizes of Profile According to Two Manufacturers</th>
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<tbody>
<tr>
<td><strong>Process 1</strong></td>
</tr>
<tr>
<td>Maximum width</td>
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<tr>
<td>Maximum depth</td>
</tr>
<tr>
<td>Maximum cross-sectional area</td>
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<tr>
<td>Maximum weight per metre</td>
</tr>
</tbody>
</table>

Some specific design awareness allows the achievement of the right characteristics:

- Have a uniform wall thickness
- Have simple, soft lines and radiused corners
- Be symmetrical
- Have a small circumscribing circle
- Not have deep, narrow channels.

#### 5.4.2.1 Wall Thickness

Small wall thicknesses require higher extrusion force (or, alternatively, a lower extrusion speed) and result in faster die wear. For simple, cost-effective, single pass drawing, wall thicknesses of less than 3 mm should be avoided.

#### 5.4.2.2 Avoid Sharp Corners

Very sharp corners are difficult to produce consistently because the die wears very easily. Specifying a radius of 1 mm is often sufficient. In general, soft contours are to be preferred wherever the functionality of the profile allows.

#### 5.4.2.3 Symmetry

Wherever possible, profiles should be designed to be symmetrical so that the shear centre is coincident with the centre of gravity. In an asymmetric profile, loads on the profile (including those introduced in manufacture) will result in torsional stresses and result in twisting. Unbalanced (asymmetric) profiles tend to twist during the drawing operations: tight geometric tolerances will require longer setup time and more complex tooling development.
5.4.2.4 Be Compact

Profile cross-sections with a low aspect ratio are easier to produce. The profile fits into a smaller circumscribing circle so the die will be smaller and stronger and the tolerances smaller.

5.4.2.5 Avoid Deep Narrow Channels

For profiles with channels, the depth of the channel should not exceed three times the width, otherwise the strength of the die will be compromised. A slightly higher ratio (1:4) can be achieved if the bottom is semi-circular and the corners at the opening have a large radius or are tapered.

5.4.2.6 Avoid Hollow Chambers

While hollow chambers can be formed in extruded profiles, the die is more complex and less robust. As a result, the product uniformity and die life, as well as productivity, are reduced.

5.4.3 Functional Design

Some advantages of using profiles rather than flat bars stem from the ability to integrate features into the design that will aid subsequent assembly processes such as mounting and jointing, as illustrated in Figure 54.

The lug on the end of the profile (1) can be made to match existing moulded supports. The channel (2) can be dimensioned to hold captive a hexagonal-headed bolt for attaching jointing plates. Fins (3) reduce skin effect and increase the surface area and, therefore, heat dissipation allowing the bar to run at lower temperature. The thin central section (4) also reduces skin effect.

![Figure 54 - Profile cross-section showing mounting lugs and slots for bolt-head](image_url)

5.5 Electrical Design Considerations

5.5.1 Skin Effect

Eddy-current effects in profiles can be reduced with respect to rectangular bars because a significantly higher proportion of the copper conductor material can be located further from the centre of the magnetic field. Because skin effect is reduced, the amount of material required is reduced.

This is particularly important where two or more conductors of the same phase are placed side by side. In this configuration the current density in some areas of the bars is comparatively very low, so the bars can be shaped to remove this ineffective material.

For slim profiles – where the material thickness does not exceed 25 mm – an approximate way to assess skin effect is to calculate the average profile thickness and obtain the relevant resistance ratio from Figure 55.
5.5.2 Thermal Dissipation

Many of the components used in switchgear generate a significant amount of heat, which is dissipated by conduction via their connections to the bars. This heat, as well as that generated in the bars, must be lost by convection and, to a lesser extent, by radiation. Ultimately, the heat is removed from the cabinet by the flow of air through the cabinet by natural convection or by forced ventilation.

Since a profile has a larger surface area than an equivalent rectangular bar, the larger air-to-bar contact surface means that more heat can be lost by convection. This is particularly true for vertically orientated profiles where the fins form channels to guide the rising air. In long vertical channels, the air moves at increasing velocity as it heats up, but it also becomes less efficient at absorbing heat from the profile and it is necessary to provide baffles to spill the air so that it can be replaced by cooler air.

On the other hand, the presence of fins and channels may significantly alter the natural air flow and cause air traps where air flow is stalled. Also, the air wetting one wall of a vertical channel may interfere with the air wetting the other walls. These effects can be reduced by ensuring that:

- Horizontal fins are adequately spaced from each other
- Vertical channels are sufficiently wide
- Vertical channels are divided so that the air flow is interrupted - at fire stops, for example – and fresh air introduced.

Figure 56 shows a thermal image of two common profiles under load.
5.5.3 Jointing and Mounting

Since profiles cannot normally be overlapped, joints are usually achieved by the use of fishplates bolted to adjacent lengths of profile. Alternatively, the profiles can be designed to include channels to retain bolt heads (as shown in Figure 54) for mounting and jointing. Connecting plates are fastened to each of the outside faces of two adjacent sections of profile, as shown in Figure 57.

In the example shown, each plate is 5 mm thick and 120 mm long and is attached by four M8-bolts to each profile. The bolt torque is 19 Nm, resulting in a high contact pressure. Assembly requires the use of a torque spanner and can be accomplished by relatively unskilled operators.
Although the contact area is rather smaller than a normal flat overlap joint, the contact pressure is rather high and efficiencies (i.e. the ratio between joint conductance and conductance of an equal length of continuous profile) of higher than 100% are possible, with freedom from hot-spots and the ability to withstand the stresses due to short-circuit currents.

5.5.4 Short Circuit Performance - Moment of Inertia

Under short-circuit conditions busbars are subject to very large electromagnetic forces which deform the bars, reducing clearance distances. For the same current, the amount of deformation is determined by the moment of inertia. A higher moment of inertia results in smaller deflections, so that busbars can be placed closer together making the installation more compact.

It must be remembered that higher momentum does not increase the short-circuit capacity of the system, which is usually limited by the short-circuit temperature rise and the effect this might have on the mechanical properties of the bars and other associated components.

Because profiles are designed to have a high proportion of their mass as far as possible from the centre (to reduce skin effect), they have a relatively high moment of inertia and deform less under short-circuit conditions.

5.6 Calculation of Moment of Inertia of Complex Sections

The following section gives an outline of the procedure for calculating the moment of inertia of a complex section about the neutral axes perpendicular to the resolved components of the applied force. It is valid only for shapes that can be broken down into elements that have neutral axes which are parallel to each other, implying that the elements are either parallel or perpendicular to each other.

For a profile, the moment of inertia about the neutral axis can be calculated by the following procedure. The cross-section of the profile is divided into regular shapes, as shown in Figure 58, in which four rectangular elements are shown. First, the moment of inertia of each element about its own neutral axis is calculated (using the formula for a simple strip). Next, the composite neutral axis is determined, the individual moments of inertia referred to it and then the overall moment determined.

![Figure 58 – Calculation of moment of inertia of a complex shape](image-url)
The moment of inertia of each segment is calculated by:

\[ I_i = \frac{bh^3}{12} \]

where the symbols are defined in Figure 59.

The position of the composite neutral axis is calculated as follows:

\[ d_c = \frac{\sum x_i y_i d_i}{\sum x_i y_i} \]

The individual moments of inertia are referred to the composite neutral axis by:

\[ I_i = I_{io} + x_i y_i k_i^2 \]

and, in total

\[ I = \sum I_{io} + \sum x_i y_i k_i^2 \]

where, for \( d_i > d_c \)

\[ k_i = d_i - d_c \]

else

\[ k_i = d_c - d_i \]