Electromagnetic Forming of Longitudinal Strengthening Ribs in Roll Formed Automotive Profiles

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Abstract

In the automotive industry, increasing ecological concerns and demands for higher performance have become lightweight construction a key aspect. Due to the gradual introduction of high strength materials on the one side, and greater consideration with regard to continuous manufacturing technologies on the other side, it is possible nowadays to address the demands that structural and complex automotive parts have to face, from the standpoint of lightweight manufacturing. Thickness, shape and impact conditions constitute the main aspects to consider for such parts and shape conditions in particular require from complex, costly and lengthy procedures, especially when discontinuous forming operations such as stamping and hydro forming procedures are selected. However, continuous forming operations like Roll Forming (RF) can prove to be advantageous and suited for scalable parts (e.g in length) and at the same time be economically reasonable. RF lines as well generally incorporate additional installations to perform multiple forming operations destined to imprint strengthening ribs perform punching operations or weld certain parts. It is in this context where the usefulness of the electromagnetic forming technology for completion of auxiliary operations can be proven, given its flexibility and reasonable investment costs.

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Electromagnetic forming (EMF) is a contact-free technique where large forces can be imparted to a conductive metallic workpiece by a pure electromagnetic interaction. The produced electromagnetic pressure can produce stresses in the workpiece that are several times larger than the material flow stress. Ultimately this can cause the workpiece to deform plastically and to be accelerated achieving high velocities. Once the velocity is imparted to the workpiece, the shape can be developed either by free or die forming.

The work described in this paper explores the potential of the EMF process to adequately form shallow longitudinal ribs or stiffeners in components previously formed utilizing an innovative concept called Flexible Roll Forming, developed at The Technical University of Darmstadt in Germany, by means of magnetic pulse forming, maintaining the integrity of the workpiece while trying to meet industry standard tolerances. Profiles exhibiting hat-like cross sections made of AHSS steels were subjected to localized impulses in order to achieve strengthening features in the roll formed part. ZStE340 steel alloy profiles were first roll formed and then inserted in the EM forming installation designed for the occasion. A high strength copper alloy (Cr-Zr-Cu) was used as a conductor for the single turn coil, placed opposite to the sidewall in the moment of the energy delivery. Formed specimens were subsequently measured to account for existing dimensional deviations.

Keywords

Profile, Finishing, Forming

1 Introduction

Shape, thickness and impact conditions are often referred as the main aspects to consider for structural automotive parts [1]. Shape conditions in particular require from complex, costly and lengthy procedures, compared to continuous forming processes. In a discontinuous process like the roll forming process, the bending occurs gradually in several forming steps from an undeformed strip to a finished profile. It constitutes a continuous manufacturing process for the production of arbitrary shaped profiles that can account for the standardization of the vehicle body components. Typical applications in the automotive industry are for example bumpers and door beams [2]. The possibility to change the length and size of the vehicle body are inherent to this process making it a very suitable technology for the new modular and adaptable concepts of the automotive (space-frame architecture) and a friendly technology for design changes.

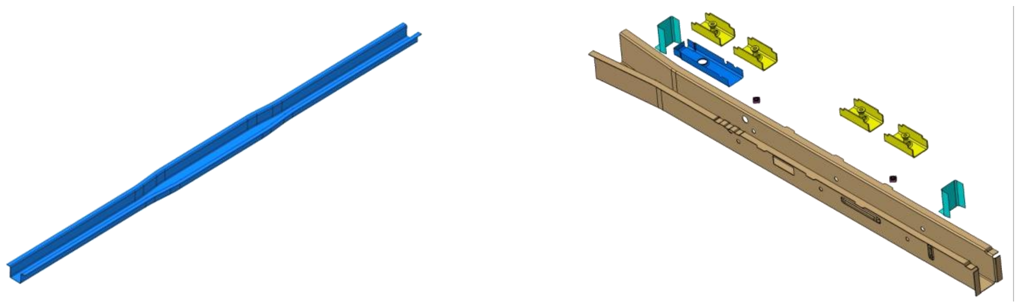


Figure 1: Example of a generic longitudinal beam (right) and a finished profile that underwent multiple complimentary operations (left)

In roll forming (RF), additional manufacturing steps needed in the components are often made in separate, independent forming cells. Stamping operations or bending operations of the extremities of the parts are required to meet functional demands in the part, and this is usually made using conventional technologies. The advantage of roll formed components could be enhanced if EMF is considered as a forming process that can produce equivalent deformation level and product variants from a pre-formed roll part, at an affordable cost, as can be observed elsewhere [3].

It is well known that with Electromagnetic Forming (EMF) large forces can be imparted to a conductive metallic workpiece by a pure electromagnetic interaction. The produced electromagnetic force can produce stresses in the workpiece that are several times larger than the material flow stress. Ultimately this can cause the workpiece to deform plastically and to be accelerated at high velocities.

The work described in this paper deals with the potential of the EMF process to impulse form stiffening features or strengthening ribs in the lateral walls of roll formed parts, made of high strength steels (ZStE340), in a continuous manner. For that, profiles with a variable cross section were first manufactured utilizing the flexible RF prototype line that was temporarily installed in Labein. The flexible Roll Forming Process concept utilized to obtain the parts was originally developed at the Technische Universität Darmstadt, and a 17 forming-stand prototype line incorporating an axis-control system was built during the course of the project in a coordinated effort by several members of the project consortium. The coil design process is then briefly described. The commercial finite element software Maxwell3D ® was used to ensure a proper magnetic field generation and concentration between coil and workpiece. The necessary energy being relevant, the coil manufacturing was undertaken to achieve an actuator that would last several shots. Experiments were carried out in Labein and results analyzed and discussed in subsequent paragraphs. Lastly, a discussion about the possibilities to integrate the technology is held and an alternative presented: a separate station comprising an electromagnetic forming device allowing for the forming of features while the main profile is being formed, at the preset line-speed. This alternative to conventional local forming could bring advantages such as reduced investment cost, derived from the lower costs of the tooling utilized versus the conventional tooling, as well as ease of integration and versatility of the process.

2 Sample preparation and coil design

2.1 Specimen preparation in the flexible roll forming line

Body in white components like transverse beams, roof beams, base side reinforcements or longitudinal beams are generally constructed on steel grades able to withstand elevated stress levels, and are generally designed taking into account crash requirements. The current study focuses on one of such materials, namely ZStE340, zinc coated micro-alloyed steel, with a thickness of 1.35 mm and mechanical characteristics illustrated in Table1. The variety of materials present in the structural frame can be variable; nonetheless all share the common property of being mechanically strong, while including the ability to absorb energy as deformation energy.

	σ_{Yield} (MPa)	σ_{UTS} (MPa)	σ_{Yield} / σ_{UTS}	εuniform (%)	E (MPa)	Poisson's Coefficient ν	Thickness (mm)
Zste340	270	355	0.76	38	210000	0.3	1.35

Table 1: Mechanical properties of ZStE340 grade

The procedure to form the strengthening ribs or stiffeners was then discussed. In conventional forming features in the longitudinal sense are stamped, creating an overall stiffening effect in the workpiece. In fact, with the EMF technology, it could be a possibility to impart energy in such a way that vertical grooves are formed in the lateral walls of the workpiece, broadening design possibilities as well as adding extra functionality. In that sense, the ability of the EMF technology to impart localized high pressure expands design possibilities, as it can be observed in other studies [4], [5].

Of all of the alternatives assessed (Figure 2) it was finally decided to proceed with the full design of an experimental setup to form a longitudinal groove, 130 mm in length, in the centre of the vertical wall. The width of the groove was set in 10 mm, setting the desired height in the order of one to two times the workpiece thickness.

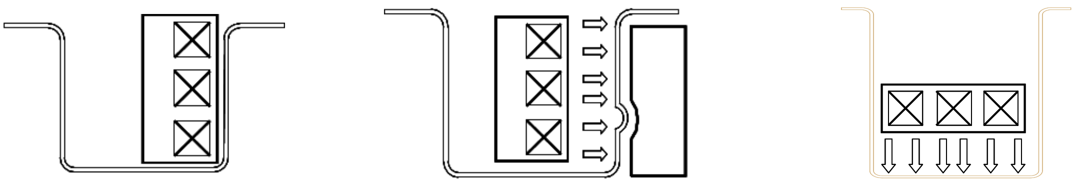


Figure 2: *Different alternatives for strengthening rib location*

The material formats were taken from a coil strip delivered by Daimler and inserted in the flexible roll forming line comprised of a laser cutting station, and several roll forming stands. The material is gradually bent with conventional rollers with the particularity that the so called flexible stands stretch-form the metal in certain areas, augmenting the size of the cross section in the central zone. The resulting workpiece is a profile with a length of 2000 mm with a variable cross section, like the one depicted in Figure 3.

Figure 3: *General view of roll formed profile (right) and close-up of the transition from narrow section to broad section.*

2.2 EMF coil design

It is well known that the material with which the magnetic actuator or coil is made must incorporate good current carrying properties as well as optimum mechanical properties [4]. It is then important the selection of a material that exhibits high conductivity while retaining considerable strength, that generally leads to a trade off in the balance of the properties. For the experiments performed in this study a Chromium-Zirconium-Copper alloy with a conductivity of 72% IACS and a tensile strength of 470 MPa was selected. It was expected that the reaction forces present during an EMF discharge be withstood by this alloy, maintaining the integrity of the coil during several discharges.

The target shape to form in the sidewall was defined afterwards. A longitudinal, strengthening rib, 130 mm long, 10 mm wide to be placed at approximately 20 mm from the bottom of the part. It was decided that the depth of such stiffener should be between 1 to 2 times the thickness of the base material, for this to be considered a proper stiffener.

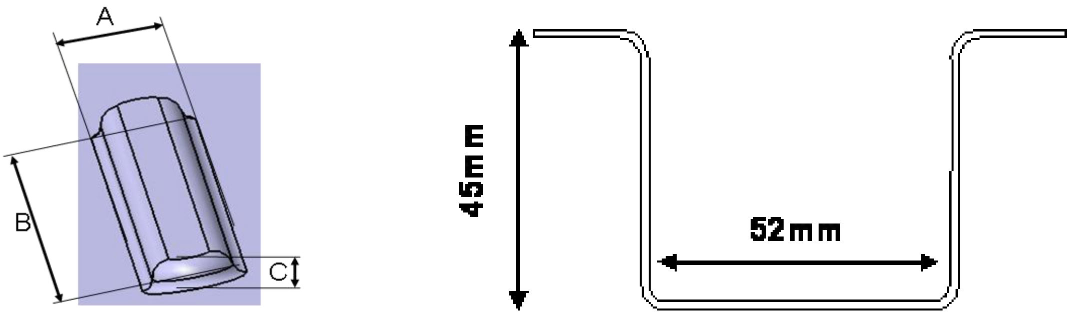


Figure 4: *Proposed shape for the stiffener (left), dimensions of the cross section in the narrow area of the workpiece*

For an actuator to emboss the described shape it was decided that a robust single turn coil was needed, that could account for the large counterforce expected in this kind of operations [6], [7]. Space limitations due to the size of the cross section were determinant in this choice too. The conceived shape is shown in Figure 5. For the validation of the proposed coil shape Maxwell 3D® was utilized. The mentioned FEM software allows for the computation of an equivalent circuit connected to the FEM model comprised of coil and workpiece, simultaneously calculating discharge current and magnetic field values.

Figure 5 shows the calculated primary current for the preset discharge parameters, with the associated peak current. The simulation was run considering that the coil is attached to a bank charged at 30kJ. The electrical parameters of the coil material were obtained in the laboratory according to standard measurements, while the electrical parameters of the steel alloy were obtained from the literature. As a result of the discharge a peak current of approximately 700 kA was obtained being the time to peak 10 microseconds. The figure on the right side shows a plot with the achieved pressure distribution on the sidewall. The calculated pressure peak at peak time was 48MPa, which gave first indications that the needed energy would be significantly higher if direct forming was desired.

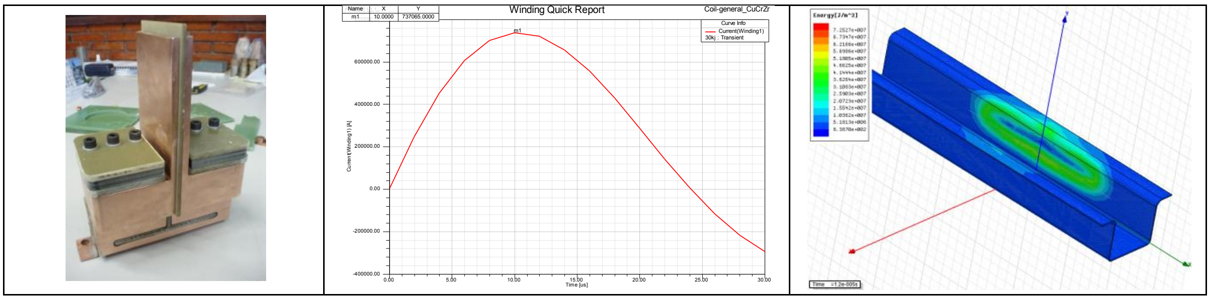


Figure 5: *Manufactured coil (left), computed discharge current (centre) and pressure distribution (right)*

Hence, the simulations validated the coil concept leading to the next step, the detailed design and manufacturing of the coil. The company Antec finished the design, manufactured the coil and reinforced it using fibreglass pre-impregnates giving the coil the desired robustness. Figure 5 (left) shows the delivered coil as it was tested at Labein's facilities.

3 EXPERIMENTAL PROCEDURE

3.1 Experimental Setup

The electromagnetic forming operation was performed using a 60KJ Magneform Energy storage control unit system where the actuator or coil is connected. The single turn coil describes a closed loop parallel to the vertical flange, being the width of the conductor of 10 mm along the direction of the groove (Figure 4). A die manufactured using Boehler's K390, heat treated and coated using a TiAlN layer to prevent premature erosion and die wear was utilized. Additionally, the die will exhibit good anti-spark properties, given the properties of the surface. If an accidental arcing occurred, the high temperatures present whilst the discharge lasts would tend to melt and erode the surface of the die, in the absence of such coating.

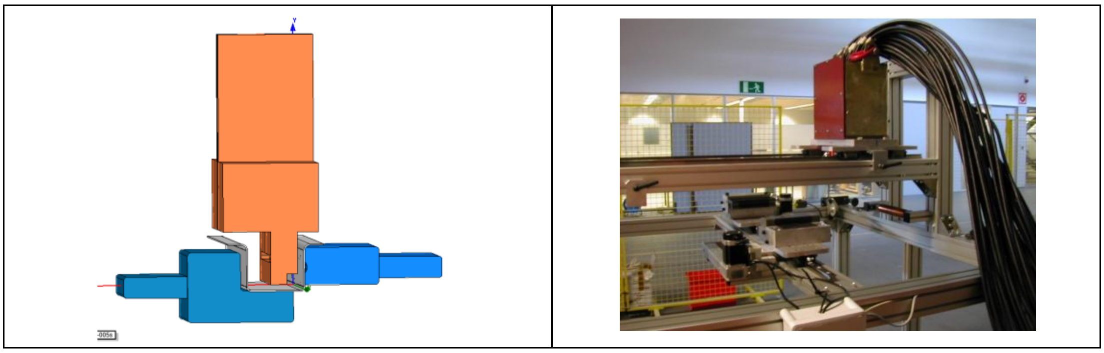


Figure 6: *Schema of the configuration of coils and dies (left), actual setup (right)*

Once the coil has been positioned, the entire assembly is attached to the pulse generator, and discharge parameters selected. The efficiency of the process is determined mainly by the confinement degree and the electrical properties of the workpiece. A low value of this parameter results in a poor energy transfer, as it is the case with the high strength steels. Generally, direct forming is not possible if the depth to be achieved is too high, and additional and more conductive materials are usually attached to the HSS in order to assist the forming. In this case, thin copper foil (0.5 mm thickness) was used in the experiments.

3.2 Implementation strategy

From the previous experiments it is concluded that the forming of features resembling stiffeners or strengthening ribs is feasible using the electromagnetic technology. Energy considerations apart, its versatility to imprint diverse features within intricate shapes could be valuable in terms of agile manufacturing. A variety of shapes can be formed, not only inside-out but also outside-in, vertical or horizontal, multiple or a sole feature with a single discharge. It certainly has proven to be a suitable technique for stringent conditions. Nonetheless, the success or failure of technologies does not solely depend on the intrinsic capabilities, but on the potential to be utilized in conjunction with other techniques. For example, one disadvantage of the roll forming process is the reduced freedom in cross-section design compared to metal extrusion; e.g. ribs within a closed profile. Results of the investigation have shown that EMF technology could be utilized or taken into consideration to emboss this shapes.

Integration, though, has to be addressed taking into account technical and economical aspects. Considering only technical factors an alternative for the EMF operation is presented, in a way that process combination is possible. The key aspect in this case is determined by the possibility to simultaneously form a feature in a moving profile, a profile that is being formed by means of forming rollers. A process lay-out like the one depicted in Figure 7 was designed and installed, where a separate forming stand comprising all necessary means to form the stiffener is installed. The profile is formed by the action of the rollers and at the same time the driven rollers would guide the profile towards the EMF stand. Without motion interruption, the EMF operation can be executed once the profile reaches the specified point where the stiffener needs to be inserted.

This kind of combination strategy can constitute a real advantage over more conventional operations and can enhance the possibilities of process like the flexible roll forming.

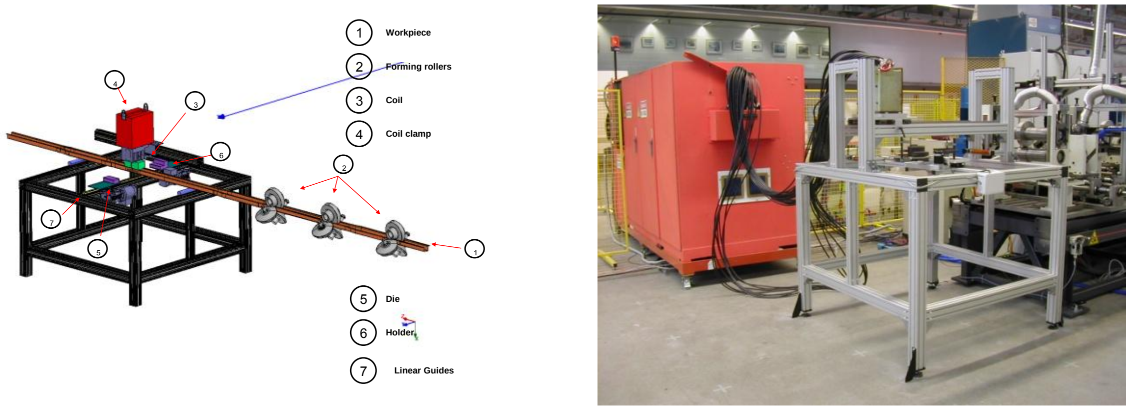


Figure 7: *EMF stand incorporating a coil that releases forming energy to moving workpiece (right)*

4 RESULTS

The experimental results obtained in the experimental try-outs are summarized in Figures 8 and 9, where the final formed configuration of a sample piece can be observed. Zste340 steel was formed using energies ranging form 21 to 45 KJ until the shallow rib was achieved in the vertical wall. Figure 8 shows a ZStE340 sample exhibiting a stiffener when a 45 kJ and an auxiliary driver were used.

Figure 8: *ZStE 340 profile with strengthening rib located in the central section*

The workpieces were then measured and compared against the theoretical geometry to account for significant deviations. It was noted that certain flange length located right above the affected area showed a deflection of 0.86mm. The defect arose as a consequence of the proximity of the coil to the flange, and insufficient blankholder-part adjustment. Even though the distance between coil and part is considerable in that area, the strength of the magnetic field is such that produces the mentioned effect.

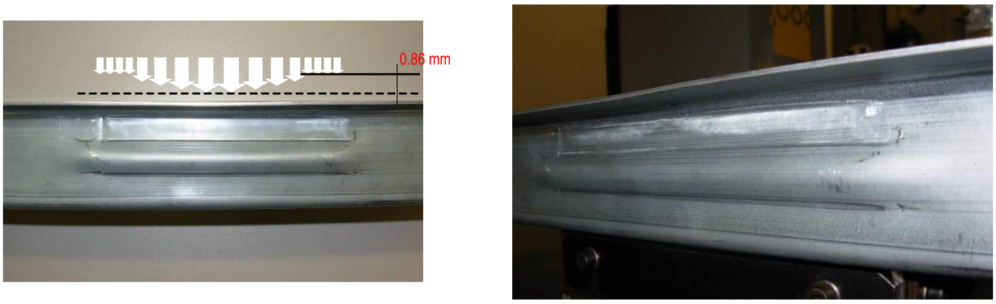
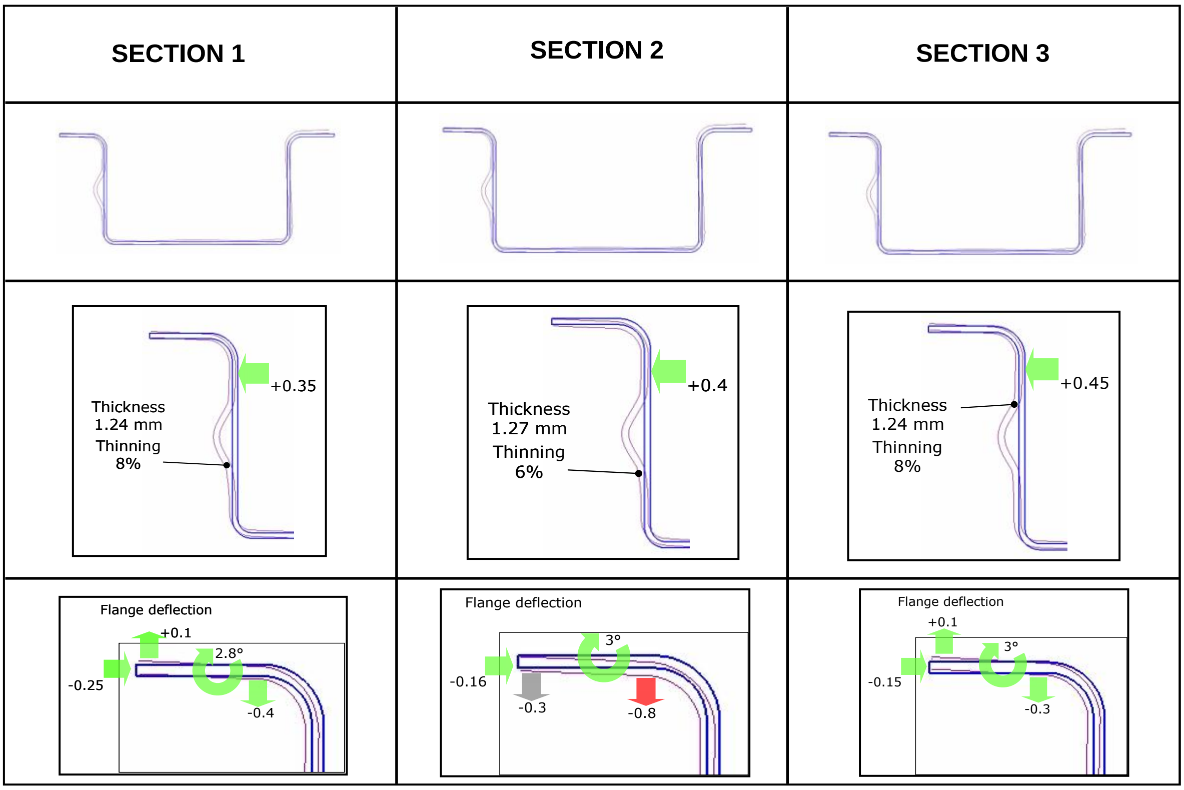


***Figure 9:** Measured flange deflection (left) and close-up of stiffener (right).*

Three sections were defined in the middle zone in order to investigate the stiffener characteristics on the wall and to evaluate the geometrical deviation to reference cad data. Two different sides were scanned, the internal and external sides. The distance between the curves represents the component thickness. An average thinning of 8% was detected and a flange deflection angle varied from 0.1 to 0.3 mm.

The desired stiffener shape was achieved in the process keeping the stiffener dome height in the range of one to two times the thickness of the base material. It was observed that the cavity was not filled fully but nevertheless an approximate shape was obtained. Visual inspection of the affected areas showed slight roughness and surface quality affectation of the surface coating.



5 CONCLUSIONS

The forming of features resembling stiffeners or strengthening ribs is feasible using the electromagnetic technology. ZStE340 steel was formed using energies ranging form 21 to 45 kJ until the shallow rib was achieved in a vertical wall achieving the desired objective. The advantage of roll formed components could be enhanced if EMF is considered as a forming process that can produce equivalent deformation level and product variants from a pre-formed roll part. When considering implementation, the integration has to be addressed taking into account technical and economical aspects. In this case it is determined by the possibility to simultaneously form a feature in a moving profile, a profile that is being formed by means of forming rollers. An integration concept has been presented that can account for the manufacturing of scalable parts combining EMF and flexible roll forming technologies. This kind of combination strategy can constitute a real advantage over more conventional operations and could enhance the possibilities of process like the flexible roll forming.

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