WORKING PRINCIPLE
OF AN ELECTROMAGNETIC WIPING SYSTEM

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In galvanizing lines, the gas knife wiping device works well for controlling the zinc coating thickness up to 2 to 3 m/s strip velocities. But for higher velocities, a strong liquid zinc splash risk forbids the gas pressure increase, which would be necessary to keep the same thickness control efficiency of the knives. That is why a complementary electromagnetic wiping system, whose purpose is to pre-wipe the liquid zinc before the gas knives take over, is presented here. After mentioning different kinds of AC and DC possible electromagnetic solutions, a DC field electromagnetic brake (EMB) system based on the use of permanent magnets is selected for a future experimental implementation. In order to better understand the electromagnetic and fluid mechanics phenomena, an analytical model and then different numerical models are presented here. These models show an interesting wiping effect on the liquid zinc, which seems promising for a future experimental pilot design.

List of symbols:
- $B_0$: imposed magnetic flux density, T
- $B$: magnetic flux density, T
- $B_r$: magnet remanent magnetic flux density, T
- $E$: electric field, V/m
- $I$: inductor current, A
- $j$: current density, A/m$^2$
- $A$: vector potential, T$\cdot$m
- $F$: electromagnetic volume force density, N/m$^3$
- $\mu$: zinc permeability ($4\pi \cdot 10^{-7}$ H/m)
- $\mu_{rc}$: magnetic core relative permeability (1000)
- $V_s$: strip velocity, m/s
- $\nu$: zinc velocity vector, m/s
- $p$: pressure, Pa
- $\phi$: scalar potential, V
- $\sigma$: liquid zinc electric conductivity ($2.86 \cdot 10^6$ S/m)
- $\rho$: liquid zinc density (6600 kg/m$^3$)
- $\eta$: liquid zinc dynamic viscosity ($3.5 \cdot 10^{-3}$ Pa-s)
- $\nu$: liquid zinc kinematic viscosity ($0.53 \cdot 10^{-6}$ m$^2$/s)
- $\eta_t$: liquid zinc equivalent turbulent dynamic viscosity ($3.5 \cdot 10^{-1}$ Pa-s)
- $\gamma$: liquid zinc surface tension (0.2 N/m)
- $c$: order of magnitude of liquid zinc thickness
- $t$: time, s
- $I_d$: identity matrix

1. Introduction. The results presented in this paper concern the setup of an electromagnetic wiping process based on the principle of the DC field electromagnetic brake (EMB) system. The aim of this device is to control the zinc
coating thickness in galvanizing lines. In these galvanizing lines, the wiping effect on the liquid zinc, meaning the control of the appropriate zinc layer thickness, is usually obtained due to gas knives [1, 2], which are located on each side of the steel strip above the liquid zinc pot as shown in Fig.1. For common steel strip velocities of about 2 to 3 m/s, the gas knives are efficient, reducing the natural zinc thickness from about 300 \( \mu \text{m} \) to 500 \( \mu \text{m} \) down to about 10 to 70 \( \mu \text{m} \) on each side of the strip. But for higher strip velocities (over 3 m/s), the gas knife pressure cannot be increased because of splash risks of the liquid zinc, thus reducing the efficiency of these knives. That is why the idea is to add between these gas knives and the zinc pot a complementary electromagnetic “pre-wiping” system, which must decrease the zinc thickness before the gas knives take over.

In part 2, different possible electromagnetic wiping principles are mentioned, and among these possible solutions the DC field electromagnetic brake (EMB) system, which seems the most suitable for this application, is chosen. In part 3, an analytical analysis of the EMB system is presented, which explains the basic involved phenomena. Then a 2D time-dependent electromagnetic/fluid mechanics coupled model with a deformed mesh technique, set up in a plane perpendicular to the strip, is presented in part 4. This model shows the deformation with time of the liquid zinc and, hence, the wiping effect on it. At last, in part 5 a 2D electromagnetic numerical model in a plane parallel to the strip shows the main electromagnetic phenomena like the induced current density in the zinc. The two numerical models are set up by the Comsol finite element solver [3].

2. Choice and working principle of the EMB wiping system.
There are several electromagnetic wiping principles, which are based on the use of a single phase high frequency (about 100 kHz) single or double pin-shape inductor, producing a longitudinal magnetic flux (LF) or a transverse magnetic flux (TF) configuration with respect to the strip. This inductor is wrapped around the strip [4] at several centimetres above the zinc bath and creates Lorentz forces, which compress the liquid zinc. This inductor, when located directly over the zinc meniscus, just where the strip comes out of the bath [5], compresses then this meniscus,
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which also gives a liquid zinc thickness decreasing just above this area. In this case, it is called a “meniscus pressure” (MP) system.

Each of these former electromagnetic wiping systems has advantages and disadvantages. Both LF and TF configurations need a high frequency induction generator and give a strip overheating due to the induced eddy currents, which may be excessive and give galvannealed instead of galvanized material. Because of the low electric efficiency, these inductive configurations require a high power level. The MP configuration needs also a high frequency induction generator and, like the LF and TF systems, they all present an electric arcing risk due to the high frequency inductor voltage and the proximity of the liquid zinc, whose free surface is often unstable. In spite of their interesting electromagnetic strip centering abilities, these three configurations are complicated to implement. This is why the choice of the implementation of the electromagnetic brake (EMB) system configuration, using permanent magnets, has been made. Its main disadvantage is that it does not center the strip, which, on the contrary, is attracted by the magnets. This requires that the strip must be well tended by the rolls. But the major advantage is that it works due to permanent magnets, therefore, with no need of any induction generator and no electric power consumption, which makes it economic and very simple to implement. That is why this EMB configuration is adopted for a deeper comprehension due to the analytical and numerical modeling of the phenomena presented in the next parts and also for a future experimental pilot design based on this principle.

As shown in Fig. 2, this system is a DC magnetic field inductor configuration put around the steel strip [6]. The DC magnetic field of this inductor is created here by permanent magnets, but can also be created by DC current coils. This system is based on the well known “electromagnetic brake” principle, which is used in buses or trucks. But the metallic solid part, in which the inductor creates a braking force, in these automotive applications is replaced by the liquid zinc, which has an upcoming velocity close to the upcoming steel strip velocity. The mainly vertically moving zinc with a velocity \( \mathbf{v} = (v_x, v_y, 0) \) encounters the magnetic poles alternation (north to south) of the magnets producing the mainly horizontal (along \( x \)) magnetic flux density, and, hence, “sees” a resulting magnetic flux

![Diagram](image)

Fig. 2. The electromagnetic brake (EMB) configuration principle.
variation according to the Lenzs law. Explained in a simplified manner, this gives a horizontal (along $z$) induced current density in the liquid zinc $j \approx \sigma (v \times B)$. This current density, coupled with the magnetic flux density $B$, produces a volume force density $F_v = j \times B$, whose module is approximately equal to $F_v = -\sigma B^2 v_y$. As $j$ and $B$ are mainly horizontal ($j$ along $z$ and $B$ along $x$), the resulting volume force density $F_v$ is mainly vertical (along $y$) and oriented downwards, opposite to the zinc velocity, thus providing the expected braking or wiping effect in the liquid upcoming zinc.

Apart from the basic principle briefly described here, the real efficiency of the device depends on the way how the electric currents close themselves up in the layer. Indeed, according to the complete expression of the Ohms law (cf. Eq. (4) in Section 3.2), there exists an electric field $E$, which may balance (sometimes totally) the term leading to a significant change of the electric current density $j$ distribution in the liquid layer. It is clear that this may affect the corresponding Lorentz forces distribution. The present situation is analogous to a Hartmann flow, i.e., a liquid flowing through a transverse DC magnetic field [7]. The latter phenomenon will be analyzed in more details in Section 3, hereafter.

3. Analysis of the electromagnetic brake (EMB) configuration.

It is of interest to analyze an ideal situation to have a better understanding of the electromagnetic braking phenomenon.

3.1. The main non-dimensional parameters. In the electromagnetic brake configuration, the main parameters involved in the problem are the following.

The magnetic Reynolds number [7]

$$R_m = \mu \sigma V_s e,$$

with $\mu$, $\sigma$, $V_s$ and $e$, respectively, being the magnetic permeability, the electric conductivity of the liquid layer, the velocity of the strip and the thickness of the layer. The magnetic Reynolds number quantifies the importance of the magnetic field created by the induced electric currents compared with the applied one. For $V_s = 3 \text{ m/s}$ and $e = 300 \mu\text{m}$, the value of $R_m$ is 0.003. This small value indicates that the applied magnetic field is weakly disturbed.

The Hartmann number $H_a$ [7]

$$H_a = \left(\frac{\sigma B^2 e^2 \nu}{\rho \nu}\right)^{1/2},$$

with $\nu$ being the kinematic viscosity and $\rho$ the liquid density. The Hartmann number is interpreted as the ratio of electromagnetic forces to viscous ones. For $B = 1 \text{T}$, the Hartmann number is 8.57. This means that the Lorentz forces are dominant in this type of problem.

The hydrodynamic Reynolds number [8]

$$Re = \frac{V_s e}{\nu}.$$

The Reynolds number is generally used to characterize the flow regime (laminar or turbulent). In the present case, its quite large numerical value equal to 1700 indicates that the nature of the flow lies in the transition region between the two regimes.
3.2. The heuristic model. In order to have a better understanding of the phenomena created by the effects of a DC magnetic field on a moving liquid metal strip, it is of interest to analyze an ideal geometrical situation shown in Fig. 3. It consists in considering an infinitely long liquid metal strip under the influence of a transverse DC magnetic field. We use the classical MHD approximations as detailed, for example, in [7].

The model simplifications are the following. Firstly, steady state conditions are assumed to hold. We suppose that the magnetic field is constant and uniform along the y-direction, thus neglecting the entry effects. The velocity field is unidirectional along the y-direction and depends only on the transverse coordinate x, i.e., \( v = (0, v(x), 0) \). Furthermore, the electric current density vector \( j \) is supposed to have a single component along the z-direction, i.e., \( j = (0, 0, j_z(x)) \). The magnetic field induced by the induced electric current density may be neglected. Finally, the flow is supposed to be laminar, and the effects of gravity are neglected. The presence of a steel strip is not taken into account.

In the frame of the above hypotheses, let us write the equations governing the phenomena.

Electromagnetic aspects. The Maxwell equations reduce to the z-projection of the Ohms law:

\[
j_z = -\sigma \frac{\partial \phi}{\partial z} - \sigma v B,
\]

with \( \phi \) denoting the electric scalar potential.

The electric current density conservation requires that

\[
\text{div } j = -\sigma \frac{\partial^2 \phi}{\partial z^2} = 0.
\]

Hence, the quantity \( \partial \phi / \partial z \) must be a constant. It is noteworthy to observe from (4) that the scalar potential gradient may counterbalance the ‘\( vB \)’ term and thus modifies the electric current density distribution within the liquid layer. This fact may also be retrieved in the expression of the single Lorentz force component \( F_y \) along the y-direction, namely,

\[
F_y = -\sigma B \frac{\partial \phi}{\partial z} - \sigma B^2 v.
\]
It is clear from (6) that the braking effect depends on the scalar potential distribution, which is also linked to the closure of the electric current near the layer edges ($y = \pm \infty$).

**Hydrodynamic aspects.** The liquid motion is governed by the Navier–Stokes equations, in which the Lorentz force $j \times B$ is introduced. Since the flow is unidirectional, many simplifications may be achieved as in the Couette flow [7]. Consequently, the motion equations finally is reduced to a single projection along the $y$-direction. Using the expression of the body force in Eq. (6), we have:

$$0 = -\frac{\partial p}{\partial y} - \sigma B \frac{\partial \phi}{\partial z} - \sigma B^2 v + \rho \nu \frac{dv^2}{dx^2},$$

(7)

where $p$ denotes the pressure.

**The boundary conditions.** For the electric current density and the scalar potential the value of the constant $\partial \phi / \partial z$ depends on the real conditions at infinity in the $z$-directions. If we assume that the two edges of the liquid layer in the $z$-direction are connected by the liquid metal outside the magnet, then the potential difference along the $z$-direction is negligible and the value of $\partial \phi / \partial z$ is simply zero.

It is important to note that the latter condition means that the electric current density must close elsewhere along the edges (e.g., as illustrated in the device shown in Fig. 5 and analyzed in Section 5).

We use the no-slip condition for the velocity at the solid wall and neglect the friction of the atmosphere at the free surface, so that

$$v(x = 0) = V_s,$$

(8)

$$\left[ \frac{dv}{dx} \right]_{x=e} = 0.$$  

(9)

Owing to the fact that the flow is unidirectional, the pressure is constant through the liquid layer and thus equal to the ambient pressure everywhere [8].

**3.3. Solution and discussion.** Eq. (7) with the boundary conditions (8) and (9) may be readily solved, and we obtain the expression of the single velocity component $v$, namely,

$$v(x) = V_s \left[ \cosh(x/\delta) - \tanh(x/\delta) \sinh(x/\delta) \right],$$

(10)

with

$$\delta = \left( \frac{\sigma B^2}{\rho \nu} \right)^{-1/2} \text{ or } \frac{\delta}{e} = \left( \frac{1}{Ha} \right).$$

(11)

The characteristic length scale quantifies the thickness of the so-called Hartmann layer [7]. When the DC magnetic field is strong enough, the ratio becomes small. Then, the induced electric currents are expelled from the liquid bulk and confined in a thin layer along the wall transverse to the magnetic field, the so-called Hartmann layer. The velocity profiles are illustrated in Fig. 4 for various values of the Hartmann number. Using the previous numerical values, namely, $B = 1\, \text{T}$ and $V_s = 3\, \text{m/s}$, the value $\delta$ is $35\, \mu\text{m}$. The latter value is much smaller than the thickness of the strip. Moreover, let us consider the velocity at the free surface, whose expression is

$$v(x = e) = V_s \left( \frac{1}{\cosh(e/\delta)} \right) = V_s \left( \frac{1}{\cosh(Ha)} \right).$$

(12)

The ratio $v(x = e)/V_s$ decreases as the Hartmann increases. This confirms the braking effect.
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3.4. The transient aspects - various characteristic time scales. In the real situation, for an observer moving with the strip, the phenomenon is fully transient. Before entering the magnetic field, the velocity profile is uniform. Then the fluid is submitted to the braking effect, which modifies the profile. The time scale corresponding to the magnetic field action is the electromagnetic characteristic time:

\[ \tau_{em} = \left( \frac{\sigma B^2}{\rho} \right)^{-1}. \]  

(13)

Using \( B = 1 \) T, the numerical value of the electromagnetic time is \( 2.3 \cdot 10^{-3} \) s. The time needed to reach the steady-state conditions analyzed previously is of the order of \( \tau_{em} \). However, in the real situation, the magnet is of finite length \( l = 0.01 \) m (order of magnitude), so that the residence of the liquid layer is limited in time, and the typical time \( \tau_c \) is linked to the strip motion by:

\[ \tau_c = \frac{l}{V_s} = 3.3 \cdot 10^{-3} \text{s}. \]  

(14)

Using \( l = 0.01 \) m (order of magnitude), the typical time \( \tau_c \) is linked to the strip motion by:

\[ \tau_c = \frac{l}{V_s} = 3.3 \cdot 10^{-3} \text{s}. \]  

In conclusion, the steady-state conditions can be reached only if \( \tau_c \gg \tau_{em} \). In the present case, the latter condition is not fulfilled, and the Hartmann profile will not be reached.

4. Multiphysic coupled 2D transverse numerical model. As stated in the previous section, the magnet is of finite length, and the evolution of the liquid layer along the \( y \)-direction must be dealt with. Furthermore, due to the braking effect, it is necessary to take into account the fact that the free surface cannot remain flat. All those effects are analyzed in the present section in the geometry of a 2D transverse model.

4.1. Geometry and simplifying assumptions. In order to show the wiping effect due to the magnets configuration on the liquid zinc, a multiphysic coupled 2D time dependent transverse numeric model has been set up in a plane perpendicular to the strip, as shown in Fig. 5. The coordinate system \((Oxyz)\) and the main dimensions are shown in the figure. This problem is solved by the Comsol finite element solver. It couples the electromagnetics and fluid mechanics with the ALE (Arbitrary Lagrangian–Eulerian formulation) deformed mesh technique [3], which allows the deformation of the liquid zinc subdomain with time. As this model
is infinitely long in the $z$-direction, it does not take into account the end effects in this direction. The steel strip itself is not taken into account either and is simply replaced by the left vertical boundary, which has a given upcoming velocity $V_s = (0, V_s, 0)$ with a non-null vertical $y$-component, which takes the liquid zinc in the vertical upward $y$-direction. This velocity vertical component $V_s$ is introduced as increasing with time ($V_s = 3t$), making it easier for the time-dependant solver to start. The left vertical boundary is also a symmetry plane so that only the half of the real problem is modelled here. The liquid layer thickness is fixed at the inlet and outlet of the fluid domain (see Fig. 5) only at the initial state.

Two opposite-oriented magnets (remanent magnetic flux density $B_r = 1$ T, which is of the same order of magnitude as neodymium magnets, which could be used here) are set on a vertical magnetic core (magnetic core relative permeability $\mu_{rc} = 1000$), which reinforces the magnetic field in the active area near the liquid zinc layer, whose initial shape is a trapezoid larger at the bottom than at the top, as shown in Fig. 5, which facilitates the starting of the liquid zinc deformation with time. The permanent magnets should be located several centimetres above the zinc bath. It is possible to put them in a thermal insulating box so that they do not lose their remanent field with the zinc temperature.

4.2. Model definition. Both the electromagnetic and fluid mechanics models are set in an ALE frame, which enables the deformation of the liquid zinc domain and the complementary surrounding air domain with a corresponding mesh deformation. The electromagnetic model is a perpendicular induction current model with the unique scalar $A_z$ component of the vector potential $A$ and including a diffusion term and a Lorentz force term depending on $A$ and the local liquid zinc velocity $v$. The corresponding induced current density $j$ (which has a unique non null component $j_z$), coupled with the magnetic flux density $B = (B_x, B_y, 0)$ in the liquid zinc layer, gives an electromagnetic volume force density, whose vertical component tends to brake the zinc. At each time step this calculated electromagnetic volume force density is entered as a volume force density source term in the fluid mechanics model (Navier–Stokes equation), which determines the correspond-
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ing velocity field $\mathbf{v} = (u, v, 0)$ and pressure $p$ in the deformed liquid zinc domain. All the domains are active in the electromagnetic model and the boundary conditions are magnetic insulation at all three top, right and bottom boundaries and electric insulation at the left vertical boundary. In the fluid mechanics model, only the liquid zinc domain is active and the boundary conditions are the following:

- on the left vertical boundary $V_s = 3t$, with $t$ being the time;
- on the horizontal top and the bottom boundaries imposed pressure (zero at bottom and hydrostatic pressure on top);
- on the right boundary (free surface) normal stress tensor condition including the surface tension $\gamma$ [9].

At last, about the moving mesh ALE model (which is not detailed here), the corresponding boundary condition at the right boundary (which is the free surface) of the zinc domain is to force the normal mesh velocity to follow the normal liquid zinc velocity. This gives the mesh deformation about time.

In order to take into account in a simplified way the turbulent flow due to a high Reynolds number in this laminar model, an “equivalent turbulent dynamic viscosity” $\eta_t$ equal to 100 times the real viscosity $\eta$ is chosen. At last, a surface tension $\gamma$ is taken into account on the free surface of the zinc (right boundary of the zinc domain), which smoothes possible free surface oscillations and helps the solver to converge.

The electromagnetic model equation is (the layer is supposed to be iso-potential):

$$\nabla \times \left( \mu^{-1} \left( \nabla \times \mathbf{A} - \mathbf{B} \right) \right) - \sigma \mathbf{v} \times \left( \nabla \times \mathbf{A} \right) = 0.$$  \hspace{1cm} (15)

The fluid motion equations (Navier–Stokes equation and flow rate conservation) are:

$$\rho \frac{\partial \mathbf{v}}{\partial t} + \rho (\mathbf{v} \cdot \nabla) \mathbf{v} = \nabla \cdot \left[ -p \mathbf{I} + \eta_t \left( \nabla \mathbf{v} + (\nabla \mathbf{v})^T \right) \right] + \mathbf{F}_v,$$

$$\nabla \cdot \mathbf{v} = 0.$$  \hspace{1cm} (16)

These coupled equations also combined with the ALE deformed mesh model give the evolution of the zinc shape with time.

In order to handle local numerical instabilities, a coefficient of isotropic artificial diffusion is added to the already existing diffusion, so that the corresponding modified Reynolds number cannot exceed 2.

The discretisation of the magnets region uses Lagrange-quadratic elements and thus does not require a large number of elements.

4.3. Modelling results. The main modelling results are illustrated in Fig. 6, corresponding to the time $t = 1$ s. This time corresponds to an approximate upcoming strip velocity of $V_s = 3 \text{ m/s}$. The calculated free surface shape of the liquid zinc subjected to the action of magnets is presented in black colour (along with the initial liquid zinc layer free surface) and the arrows show the magnetic flux density due to the magnets. Two liquid bumps of a few millimetres thick appear below the two magnet poles, which show clearly the braking and wiping effects on the liquid zinc, which is thus retained by the electromagnetic braking forces.

This transverse numerical model shows an efficient wiping effect produced by the magnet poles EMB system on the liquid zinc, thus leading to an important thickness decreasing.

5. Electromagnetic 2D in-plane numeric model. As stated above, a key issue concerns the closure of the induced electric currents. It is already
discussed in Section 3 that the efficiency of the device strongly depends on the way how the electric currents close themselves. In order to have a qualitative answer to this issue, it is of interest to analyse the electric current distribution in a plane parallel to the strip.

5.1. Geometry and simplifying assumptions. In order to study the basic electromagnetic phenomena, taking place in the EMB configuration, a simplified electromagnetic 2D numeric model is set up in the strip plane, as shown in Fig. 7, in which the main dimensions are also sketched, corresponding to the $Ox$- and $Oy$-axes. The model is infinitely long in the $Oz$-axis direction, which implies that the real zinc thickness and the presence of the steel strip itself are not taken into account. This is justified by the fact that the electric current density profiles are almost uniform as shown in the previous section. The zinc, being considered here as an equivalent solid having the same velocity as the strip, has an upcoming velocity $V_s = 2 \text{m/s}$ parallel to the $y$-axis (the $y$-component of $v$). The first upper hatched area corresponds to an imposed induction vector $\mathbf{B}_0 = (0, 0, B_{0z})$ parallel to $Oz$ produced by a north-pole magnet giving a positive $z$ induction component $B_{0z} = 0.1 \text{T}$. The second lower hatched area corresponds to an imposed induction vector $\mathbf{B}_0 = (0, 0, -B_{0z})$ parallel to $Oz$ produced by a south-pole magnet giving a negative induction $z$-component. Thus, the upcoming zinc is submitted to an alternating magnetic flux density with a sign change due to this double pole configuration, which allows the closure of the electric current in the $Oxy$-plane.
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Fig. 7. 2D electromagnetic model geometry definition.

and provides a better efficiency than in the case of a single pole configuration, according to Lentzs law.

5.2. Model definition. When the zinc encounters the magnetic field \( B_0 \) induced by the two magnets, the configuration induces a current density according to the Lorentz equation:

\[
\sigma (E + v \times (B + B_0)) = j; \tag{17}
\]

\[
\nabla \times E = 0; \tag{18}
\]

\[
\nabla \times B = \mu j. \tag{19}
\]

The zinc velocity is given by \( v = (0, v, 0) \).

In this model the magnetic flux densities \( B \) (induced part) and \( B_0 \) (imposed part) have only the non-null \( z \)-components \( B_z \) and \( B_{0z} \). The currents and the electric field have no \( z \)-components. Solving for \( B_z \) yields the following scalar partial differential equation:

\[
-\nabla \left[ \nabla B_z + \mu \sigma v_y (B_z + B_{0z}) \begin{pmatrix} 0 \\ -1 \end{pmatrix} \right] = 0. \tag{20}
\]

The boundary conditions are the Dirichlet conditions \( B_z = 0 \) at all outer boundaries. This model is solved by the Comsol finite element solver [3].

5.3. Modelling results. The main results are illustrated in Fig. 8. The induced magnetic flux density \( z \)-component \( B_z \) is in grey scale. The streamlines show the induced current density flow. At last, the arrows show the repartition of the volume force density equal to \( j \times (B + B_0) \).

The volume force density is mainly oriented towards the negative \( y \)-direction, giving an efficient braking effect on the major part of the zinc width, except on the two left and right ends, where it has a more horizontal \( x \)-component due to the current density looping. Nevertheless, this end effect can be reduced by optimizing the geometry like an increase of the strip (and zinc) width and also a horizontal overlapping of the magnets on the strip width.
6. Conclusion. In galvanizing line installations, the classical wiping by means of gas knives is efficient until strip velocities of about 2 to 3 m/s. But when the velocity exceeds these values, this gas wiping is no more sufficient because liquid zinc splash risks prevent the gas pressure increase of the knives, and there it is interesting to have an additional electromagnetic wiping system, which precedes the gas wiping system. Thus, this electromagnetic wiping system can remove a large proportion of the liquid coating, and so it is easier for the gas wiping system to take over without gas pressure increase. Different possible electromagnetic wiping solutions are mentioned. Those, which are based on eddy currents and use high frequency inductive equipment, are complicated to implement and have a major disadvantage, which is the possible excessive heating of the strip. That is why the choice of the implementation is made for an electromagnetic wiping system, which utilizes a magnetic DC field produced by permanent magnets and is based on the electromagnetic brake (EMB) system, which has some main advantages like no power consumption and no need of a generator, making it simple to implement.

In a first step, the basic electromagnetic and fluid mechanic phenomena involved in this EMB process are analytically analysed. Then it is analyzed numerically and modelled by the Comsol finite element solver. A time-dependant 2D multiphysic electromagnetic/fluid mechanics coupled numerical model, including the ALE deformed mesh technique, which is set up in a plane perpendicular to the strip, is presented. This model shows the liquid zinc deformation with time and also shows clearly the braking effect on it. Then the basic electromagnetic phenomena are modelled in the strip plane in order to have a clue on the actual distribution of the current density flow in the zinc and the braking volume force density. It is shown that the use of two magnets with opposed magnetic fields is much more efficient than the use of a single magnet.
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These promising features concerning this EMB wiping configuration must be considered as some first attempts to approach the understanding of the basic phenomena involved in such a complex process. The next steps will be a 3D-coupled modelling in order to better understand the end effects problems, and, finally, the design of a reduced scale experimental galvanizing pilot, which will be fitted out with such an EMB wiping system.

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