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Thought Analysis on Relaxation

and

General Principle to Find Relaxed State

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Abstract

A thought analysis on relaxation is presented to lead to a general principle applicable to all dynamical systems to find the relaxed state. The general principle is applied to the energy relaxation of the MHD plasma to lead to the relaxed state of $\nabla \times \mathbf{B} = \lambda \mathbf{B}$ and the mode transition condition without using the concept of helicity. The present theory permits the quasi-steady energy flow through the boundary surface and leads to a more general relaxed state for plasmas having spatial dependent resistivity, that connects directly to the experimental fact of $\mathbf{j} = 0$ near the wall.

Keywords : thought analysis, MHD relaxation, energy minimum, minimum decay phase, relaxed state, dynamical systems, force-free fields, helicity, quasi-steady, minimum entropy production

The energy-relaxation theory of the magnetohydrodynamic (MHD) plasma with the concept "helicity" by Taylor has been applied successfully to many experiments such as the reversed field pinch (RFP) and the spheromak.[1,2] The relaxed state derived by Taylor is expressed by the force-free field of $\nabla \times \mathbf{B} = \lambda \mathbf{B}$, where λ is a constant and the MKS unit is used here. However, recent experimental data have clarified that in the ZP-2 device, which is a simple toroidal Z pinch without toroidal coiles for the toroidal flux and therefore has no initial total helicity, there still appears the relaxation of the field configuration to lead to the spontaneous generation of the toroidal field within a few tens of μs in the produced toroidal plasma.[3,4] The relaxed state of the plasma becomes to have finite total helicity and to be close to the state of $\nabla \times \mathbf{B} = \lambda \mathbf{B}$ that cannot be determined by the initial total helicity,[3,4] contrary to the theory by Taylor.[1,2] On the other hand, three-dimensional MHD simulations have also clarified that the relaxation takes place to lead to the state given nearly by $\nabla \times \mathbf{B}$ $= \lambda \mathbf{B}$.[5] An important point to consider is that in the MHD simulations they do not solve any equations for hilicity but they do solve equations of three conservation laws on mass, momentum, and energy (or equivalently the entropy equation) together with Maxwell's equations and Ohm's law, where $\mu_o \, \mathbf{j} = \nabla \times \mathbf{B}$ is used by neglecting the displacement current. This fact indicates that the quantity of helicity does not dominate the process of relaxation but is used for a kind of classification or labeling to describe some part of the process. The both results by the experiments and the MHD simulations mentioned above suggest that we need a new theory for obtaining the relaxed state without using the concept of helicity. In this letter, a thought analysis on the concept of relaxation is presented to lead to a general principle to find the relaxed state. In the thought analysis, we investigate logical structures, ideas or thoughts used in the objects being studied, and try to find some key elements for improvement and/or some other new thoughts which involve generality.[6] The general principle derived here is applied to the MHD plasma to lead to the relaxed state of $\nabla \times \mathbf{B} = \lambda \mathbf{B}$ without useing the concept of helicity, and therefore is shown to cover all the experiments of the RFP, the spheromak, and the simple toroidal Z pinch together with the three-dimensional MHD simulations.

First, we show a thought analysis on relaxation where we try to analyse the concept of "relaxation" in order to understand the basic structure of the thoughts included in it. We now consider a dynamical system that consists of quantities $\mathbf{q}(t, \mathbf{x})$. Here, t is time, $\mathbf{x}$ denotes m-dimensional space variables, and $\mathbf{q}$ represents a set of physical quantities having n elements, some of which are vectors such as $\mathbf{B}$ and $\mathbf{j}$, and others are scalors such as the mass density, the energy density, the specific entropy and so on. Time evolutions of $\mathbf{q}$ are given by definite equations such as the conservation laws of mass, momentum, and energy, and the Maxwell equations or the laws ruling the dynamical system in general sense. Integrating one element, w, such as the energy density in $\mathbf{q}$ over the space volume, we can define a global quantity of $W(t)$, such as the energy of the system, as $W(t) = \int w(\mathbf{q})\, d\mathbf{x}$. Following the time evolution of $W(t)$, we would observe rapid decay phases and quasi-steady slow decay ones (or if $W(t)$ is the total entropy, then we observe rapid increasing phases and slow ones). We then recognize the rapid decay phases as "the ralaxation phase" of the quantity W of the system, and also the quasi-steady slow phases as "the relaxed state phase" of that. We therefore come to the following main element of thoughts on the relaxed state of W of the system as a definition:

$$\textit{relaxed state of } W \;=\; \textit{quasi-steady and minimum } \;|\, dW/dt \,|\,. \qquad (1)$$

This definition would be common for all dynamical systems including physical systems, biological systems, and/or economical systems. We now use the variational technique in order to find distribusiotns of $\mathbf{q}(t^{o}, \mathbf{x})$ with respect to $\mathbf{x}$ of the relaxed state, where t^{o} denotes the quasi-steady phase. When the boundary values of some elements q_j in $\mathbf{q}$ are given, the boundary conditions of the variations $\delta\mathbf{q}$ are then written as { $\delta q_j \; = \; 0$ at the boundary }. Since we minimize the value of $|dW/dt|$ under a given value of W in the quasi-steady phase, which is the global constraint on W, with respect to the variations δq, we obtain the following expression for a general principle to find the relaxed state of W:

$$\delta F \; = \; 0, \tag{2}$$

$$\delta^2 F \; > \; 0, \tag{3}$$

$$\delta q_j \; = \; 0 \quad \text{at the boundary} \, , \tag{4}$$

where F is the functional defined by $F = |dW/dt|$ - αW; δF and $\delta^2 F$ are the first and second variations of F; and α is the Lagrange multiplier.

We now apply the general principle of Eqs.(2)-(4) to the derivation of the ralaxed state of energy in the MHD plasma. For simplicity it is assumed here, as the same as in the theory by Taylor,[1,2] that the plasma internal energy is negligible compared to the magnetic energy $W_m \; = \; \int (B^2/2\mu_o)dv$, which is therefore the global quantity W discussed above. Using Maxwell's equations, the vector formula of $\nabla \cdot (\mathrm{a} \times \mathrm{b}) = \mathrm{b} \cdot \nabla \times \mathrm{a} - \mathrm{a} \cdot \nabla \times \mathrm{b}$, Ohm's law of $\mathbf{E} = \eta \mathbf{j}$, and the Gauss theorem, we obtain $dW_m/dt = - \int \eta \, \mathbf{j} \cdot \mathbf{j} dv - \oint (\mathbf{E} \times \mathbf{H}) \cdot d\mathrm{s}$, where $\oint$ denotes the surface integral over the boundary. We assume here the resistivity η to be constant, for simplicity. Substituting W_m and $|dW_m/dt|$ respectively to W and $|dW/dt|$ in the general principle of Eqs.(2)-(4) to find the relaxed state, we obtain the followings,

$$\delta F \; = \; \int (2\eta \, \delta \mathbf{j} \cdot \mathbf{j} - \frac{\alpha}{\mu_o} \delta \mathbf{B} \cdot \mathbf{B}) dv \; = \; 0, \tag{5}$$

$$\delta^2 F = \int (2\eta\, \delta\mathbf{j}\cdot\delta\mathbf{j} - \frac{\alpha}{\mu_o}\delta\mathbf{B}\cdot\delta\mathbf{B})dv > 0, \tag{6}$$

where the values of the Poynting vector $\mathbf{E}\times\mathbf{H}$ on the boundary surface in dW_m/dt are assumed to be given so that the surface integral terms vanish in both δF and $\delta^2 F$ by the boundary conditions of Eq.(4), for simplicity. Using $\mu_o\delta\mathbf{j} = \nabla\times\delta\mathbf{B}$, $\nabla\cdot(\mathbf{a}\times\mathbf{b}) = \mathbf{b}\cdot\nabla\times\mathbf{a} - \mathbf{a}\cdot\nabla\times\mathbf{b}$, and the Gauss theorem again, we obtain the followings from Eqs.(5) and (6),

$$\delta F = \frac{2\eta}{\mu_o^2}\int \delta\mathbf{B}\cdot(\nabla\times\nabla\times\mathbf{B} - \frac{\alpha\mu_o}{2\eta}\mathbf{B})dv + \frac{2\eta}{\mu_o}\oint(\delta\mathbf{B}\times\mathbf{j})\cdot ds = 0\,, \tag{7}$$

$$\delta^2 F = \frac{2\eta}{\mu_o^2}\int \delta\mathbf{B}\cdot(\nabla\times\nabla\times\delta\mathbf{B} - \frac{\alpha\mu_o}{2\eta}\delta\mathbf{B})dv + \frac{2\eta}{\mu_o}\oint(\delta\mathbf{B}\times\delta\mathbf{j})\cdot ds > 0, \tag{8}$$

where $\mu_o\,\mathbf{j} = \nabla\times\mathbf{B}$ is used. We then obtain the Euler-Lagrange equation from the volume integral term in Eq.(7) for arbitrary variations of $\delta\mathbf{B}$ as follows,

$$\nabla\times\nabla\times\mathbf{B} = \frac{\alpha\mu_o}{2\eta}\mathbf{B}\,. \tag{9}$$

The first integral for Eq.(9) is given as follows,

$$\nabla\times\mathbf{B} = \pm\,\lambda\mathbf{B}\,, \tag{10}$$

$$|\,\lambda\,| = \sqrt{\frac{\alpha\mu_o}{2\eta}}\,, \tag{11}$$

where the Lagrange multiplier α is assumed to be positive. It is easy to show that Eq.(10) is the solution of Eq.(9), by substituting Eq.(10) to the result of $\nabla\times\{$Eq.(10)$\}$ to lead to Eq.(9). We have now obtained the same relaxed state, Eq.(10), from the general principle without the concept of helicity, as that derived by Taylor with use of the helicity.

Using Eq.(8), we next discuss the mode transition point of the relaxed state, for example from the cylindrical mode to the mixed helical one in the cylindrical plasma.[1,2,7] We consider here the following associated eigenvalue problem for the critical perturbation $\delta \mathbf{B}$ that makes the volume integral term of $\delta^2 F$ in Eq.(8) become zero:

$$\nabla \times \nabla \times \delta \mathbf{B}_i \; - \; \lambda_i^2 \, \delta \mathbf{B}_i \; = \; 0, \tag{12}$$

with the boundary condition of $\delta \mathbf{B} \cdot ds \; = \; 0$ at the boundary, where λ_i and $\delta \mathbf{B}_i$ denote the eigenvalue and the eigensolution, respectively. The eigensolution $\delta \mathbf{B}_i$ of Eq.(12) is also the solution of $\nabla \times \delta \mathbf{B}_i \; = \; \pm \, \lambda_i \, \delta \mathbf{B}_i$, and therefore makes the surface integral term of Eq.(8) vanish. Substituting the eigensolution $\delta \mathbf{B}_i$ into Eq.(8) and using Eq.(12), we obtain the following:

$$\delta^2 F \; = \; \frac{2\eta}{\mu_o^2}(\lambda_i^2 \; - \; \lambda^2) \int \delta \mathbf{B}_i \cdot \delta \mathbf{B}_i \, dv \; > \; 0, \tag{13}$$

where Eq.(11) is used. Since Eq.(13) is required for all eigenvalues, we obtain the following condition for the relaxed state with the minimum $|dW_m/dt|$,

$$\lambda_{-1} \; < \; \lambda \; < \; \lambda_1 \, , \tag{14}$$

where λ_{-1} and λ_1 are the largest of the negative and the smallest of the positive eigenvalues, respectively. The value of λ in Eq.(10) gives the experimental parameter for the value of $\mu_o \, j/B$ at the magnetic axis in the relaxed state.[7] When the value of λ satisfies the condition of Eq.(14), the basic mode by the solution of Eq.(10) for the given boundary condition and the given value of W_m has the minimum $|dW_m/dt|$. However, the basic mode by Eq.(10) with λ greater than λ_1 for a given larger value of W_m has greater value of $|dW_m/dt|$ than the mixed mode that has the same value of W_m and consists with the basic mode by Eq.(10) with $\lambda \; = \; \lambda_1$ and the lowest eigenmode by Eq.(12). This results on the mode transition are the same as that obtained by Taylor.[1,2,7]

The experimental relaxation phenomena in the simple toroidal Z pinch in the ZP-2 device can be explained by the present theory, because of no need of the concept of helicity. Furthermore, since the present theory permits the quasi-steady energy flow through the boundary surface by the Poynting vector, as is indeed the case in most experiments, the present result reveals that the relaxations to the state of $\nabla \times \mathbf{B} = \pm \lambda \mathbf{B}$ are more general phenomena that take place in plasmas even within nonideally conducting boundary. When we introduce a fixed spatial dependence of the resistivity like as $\eta(\mathbf{x})$, as is indeed the case in all experiments where η goes up to infinity near the boundary wall, we obtain the following relaxed state by the same procedure from Eq.(5) to Eq.(9) with use of $\mathbf{B} = \nabla \times \mathbf{A}$ instead of $\mu_o \delta \mathbf{j} = \nabla \times \delta \mathbf{B}$,

$$2\eta \mathbf{j} = \alpha \mathbf{A}, \tag{15}$$

where $\mathbf{A}$ is the vector potential. Since $\mathbf{A}$ is finite near the boundary wall, the result of the present theory leads directly to the experimental fact that the current density $\mathbf{j}$ goes to zero near the wall where η goes to infinity. By using definitions of $\eta(\mathbf{x}) = \eta_o g(\mathbf{x})$ and $| \lambda | = \sqrt{\alpha \mu_o / 2\eta_o}$, the condition of Eq.(14) can be extended to this more general case, as in Ref.7, where η_o is the value of η at the magnetic axis and the eigenvalue problem is now $\mu_o g(\mathbf{x}) \delta \mathbf{j}_i - \lambda_i^2 \delta \mathbf{A}_i = 0$. Since the first term of $|dW_m/dt|$ is in other words the entropy production rate, the relaxed state by the present theory is equivalent to the state of the minimum entropy production rate under a given value of W_m.

In conclusion, we have presented the thought analysis on relaxation to lead to the general principle of Eqs.(2)-(4) which would be applicable to all dynamical systems. We have applied the general principle to the energy relaxation of the MHD plasma to lead to the relaxed state of Eq.(10) and the mode transition condition of Eq.(14) without using the concept of helicity. The present theory permits the quasi-steady energy flow through the boundary surface and can cover all experiments of the RFP, the spheromak, and the simple toroidal Z pinch. The present theory leads to the more general relaxed state of Eq.(15) for plasmas having the spatial dependent resistivity, that connects directly to the experimental fact of $\mathbf{j} = 0$ near the wall. The relaxed state derived here is equivalent to the state of the minimum entropy production rate under a given value of W_m.

References

[1] J. B. Taylor, Phys. Rev. Lett. **33**, 1139 (1974).

[2] J. B. Taylor, Rev. Mod. Phys. **58**, 741 (1986).

[3] K. Sugisaki, J. Phys. Soc. Jpn. **56**, 3176 (1987).

[4] K. Sugisaki, J. Phys. Soc. Jpn. **57**, 4175 (1988).

[5] R. Horiuchi and T. Sato, Phys. Rev. Lett. **55**, 211 (1985).

[6] Y. Kondoh, J. Phys. Soc. Jpn. **60**, No.9 in press (1991).

[7] Y. Kondoh, J. Phys. Soc. Jpn. **58**, 489 (1989).

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