ISSN 0915-633X

NATIONAL INSTITUTE FOR FUSION SCIENCE

On the Lagrangian of the Linearized MHD Equations

J. Todoroki

(Received – May 20, 1992)

NIFS-154 Jun. 1992

RESEARCH REPORT
NIFS Series

NAGOYA, JAPAN

On the Lagrangian of the Linearized MHD Equations

Jiro TODOROKI

National Institute for Fusion Science, Nagoya 464-01

Abstract

Lagrangian for the linearized, ideal and resistive, MHD equations is discussed, by introducing the perturbation of the total pressure. In the resistive MHD equations, the Lagrangian is expressed in terms of the electric displacement vector (time integral of the electric current) as well as the plasma displacement. The NOVA and NOVA-R formulation can be derived by using the obtained Lagrangian.

Key Words: Lagrangian, linearized MHD equation, resistive MHD

In this paper, the Lagrangian for the linearized resistive magneto-hydrodynamic (MHD) equations is derived. The perturbation of the total pressure is included as a dependent variable in addition to the displacement vector and electric displacement vector, in order to separate the operator associated with the continuous spectrum in the ideal limit.[1,2]

We shall consider the MHD equilibrium, satisfying the following magneto-static equations

$$\boldsymbol{J}\times\boldsymbol{B}=\nabla P,\quad \boldsymbol{J}=\nabla\times\boldsymbol{B},\quad \nabla\cdot\boldsymbol{B}=0, \tag{1}$$

where P is the equilibrium pressure, $\boldsymbol{B}$ the equilibrium magnetic field, and $\boldsymbol{J}$ the equilibrium electric current. The simply nested toroidal magnetic surface is assumed, so that $P=P(\psi)$. Assuming that the perturbed quantities have the time dependence of the form $\exp(qt)$, we can write the linearized MHD equations in the following form [3]

$$q^2\rho\boldsymbol{\xi}+\boldsymbol{b}\times\boldsymbol{J}+\boldsymbol{B}\times\nabla\times\boldsymbol{b}-\nabla\left[\boldsymbol{\xi}\cdot\nabla P+\gamma_s P\nabla\cdot\boldsymbol{\xi}\right]=0, \tag{2}$$

$$\boldsymbol{b}-\nabla\times(\boldsymbol{\xi}\times\boldsymbol{B})+\frac{1}{q}\nabla\times(\eta\nabla\times\boldsymbol{b})=0, \tag{3}$$

where $\boldsymbol{\xi}$ is the plasma displacement and $\boldsymbol{b}$, is the perturbed magnetic field, γ_S being the ratio of the specific heat, and η the resistivity. The boundary conditions are, assuming the surrounding fixed resistive boundary at $\psi=1$, $\boldsymbol{\xi}\cdot\boldsymbol{n}=0$ and $\boldsymbol{n}\times\eta\nabla\times\boldsymbol{b}=0$, where $\boldsymbol{n}$ is the outward normal on the boundary. In the ideal case (η=0) the latter condition has no meaning.

For the ideal case, the perturbed magnetic field can be expressed in terms of $\boldsymbol{\xi}$, and the Lagrangian can be obtained. Its density can be written as

$$\mathcal{L}_I[\boldsymbol{\xi}]=q^2\rho|\boldsymbol{\xi}|^2+|\boldsymbol{Q}|^2+\boldsymbol{J}\times\boldsymbol{\xi}^*\cdot\boldsymbol{Q}+(\boldsymbol{\xi}\cdot\nabla P)(\nabla\cdot\boldsymbol{\xi}^*)+\gamma_s P|\nabla\cdot\boldsymbol{\xi}|^2, \tag{4}$$

with $\boldsymbol{Q}\equiv\nabla\times(\boldsymbol{\xi}\times\boldsymbol{B})$, $|\boldsymbol{\xi}|^2\equiv\boldsymbol{\xi}^*\cdot\boldsymbol{\xi}$, and * denotes complex conjugate. The first term in eq.(4) corresponds to the kinetic energy, and the other terms to the potential energy.[4] The eigenvalue q is real (for unstable modes) or pure imaginary (for stable modes).

When the resistivity is introduced, the self-adjointness of the linearized operator is lost, and the eigenvalue q becomes to a complex number. We shall rewrite eqs.(2) and (3) in terms of perturbed electric displacement $\boldsymbol{a}=\nabla\times\boldsymbol{b}/q$, instead of $\boldsymbol{b}$.

$$\begin{aligned}q^2\rho\boldsymbol{\xi}+\boldsymbol{Q}\times\boldsymbol{J}+\boldsymbol{B}\times\nabla\times\boldsymbol{Q}-\nabla\left[\boldsymbol{\xi}\cdot\nabla P+\gamma_s P\nabla\cdot\boldsymbol{\xi}\right]\\ -\boldsymbol{B}\times\nabla\times\nabla\times(\eta\boldsymbol{a})+\boldsymbol{J}\times\nabla\times(\eta\boldsymbol{a})=0,\end{aligned} \tag{5}$$

$$q\boldsymbol{a}-\nabla\times\boldsymbol{Q}+\nabla\times\nabla\times(\eta\boldsymbol{a})=0. \tag{6}$$

The adjoint equations are written as

$$q^2\rho\bar{\xi} + \bar{Q} \times J + B \times \nabla \times \bar{Q} - \nabla\left[\bar{\xi}\cdot\nabla p + \gamma_s p \nabla\cdot\bar{\xi}\right] \\ - B \times \nabla \times \nabla \times (\eta\bar{a}) = 0, \tag{7}$$

$$q\bar{a} - \nabla \times \bar{Q} + \nabla \times \nabla \times (\eta \bar{a}) = \nabla \times (J \times \bar{\xi}), \tag{8}$$

with $\bar{Q} \equiv \nabla \times (\bar{\xi} \times B)$. In the ideal case, the set of eqs.(7) and (8) are identical to that of eqs.(5) and (6), and the adjoint variables are either the complex conjugates of the original variables, or the original variables; however, such a relation does not hold in the resistive case. Hence, we shall introduce the new variables ξ_+, ξ_-, a_+, and a_- by the relations

$$\left.\begin{array}{ll} \xi = \xi_+ + \xi_-, & \bar{\xi} = \xi_+ - \xi_- \\ a = a_+ + a_-, & \bar{a} = a_+ - a_- \end{array}\right\}. \tag{9}$$

Equations for them can be written in the form

$$q^2\rho\xi_\pm + Q_\pm \times J + B \times \nabla \times Q_\pm - \nabla\left[\xi_\pm \cdot \nabla P + \gamma_s P \nabla \cdot \xi_\pm\right] \\ - B \times \nabla \times \nabla \times (\eta a_\pm) + \frac{1}{2} J \times \nabla \times (\eta[a_+ + a_-]) = 0, \tag{10}$$

$$q a_\pm - \nabla \times Q_\pm + \nabla \times \nabla \times (\eta a_\pm) = \pm\frac{1}{2}\nabla \times (J \times [\xi_+ - \xi_-]). \tag{11}$$

Then, it is a easy task to write down the Lagrangian deriving these equation. The Lagrangian density can be written in the form

$$\mathcal{L}_R = \mathcal{L}_0[\xi_+, a_+] - \mathcal{L}_0[\xi_-, a_-] + \mathcal{M}, \tag{12}$$

where

$$\mathcal{L}_0[\xi, a] = q^2\rho|\xi|^2 + q\eta|a|^2 + \frac{1}{2}\left[(\xi^*\cdot\nabla P)\nabla\cdot\xi + (\xi\cdot\nabla P)\nabla\cdot\xi^*\right] \\ + \left|Q + \frac{1}{2}J \times \xi - \nabla \times (\eta a)\right|^2 - \frac{1}{4}|J \times \xi|^2 + \gamma_s P|\nabla\cdot\xi|^2, \tag{13}$$

$$\mathcal{M} = \frac{1}{2}\left\{J \times \xi_- \cdot \nabla \times (\eta a_+^*) + J \times \xi_-^* \cdot \nabla \times (\eta a_+) \\ - J \times \xi_+ \cdot \nabla \times (\eta a_-^*) - J \times \xi_+^* \cdot \nabla \times (\eta a_-)\right\}. \tag{14}$$

In the next step, the perturbation of the total pressure

$$\varpi \equiv -\xi\cdot\nabla P - \gamma_s P(\nabla\cdot\xi) + B\cdot b \tag{15}$$

is introduced as the dependent variable, in order to recover the NOVA*[1,5]* and NOVA-R*[6]* equations. For this purpose, we introduce the variable $\mathcal{D} \equiv \nabla\cdot\xi$, and write the Lagrangian (4) in the form

$$\mathcal{L}_1[\xi, \mathcal{D}, \varpi] = q^2\rho|\xi|^2 + \left|\hat{Q} - B\mathcal{D}\right|^2 + J \times \xi^* \cdot (\hat{Q} - B\mathcal{D}) + (\xi\cdot\nabla P)\mathcal{D}^* \\ + \gamma_s P|\mathcal{D}|^2 + \varpi^*(\mathcal{D} - \nabla\cdot\xi) + \varpi(\mathcal{D}^* - \nabla\cdot\xi^*), \tag{16}$$

where $\hat{Q} \equiv B\cdot\nabla\xi - \xi\cdot\nabla B$, and ϖ is introduced as the Lagrange multiplier. Since $\mathcal{D}$ appears only in algebraic form without derivatives in eq.(16), by carrying out the minimization with respect to it, we can eliminate $\mathcal{D}$ from the Lagrangian. The result is

$$\mathcal{L}_{\rm I}[\boldsymbol{\xi},\varpi] = q^2\rho|\boldsymbol{\xi}|^2 + |\hat{\boldsymbol{Q}}|^2 + \boldsymbol{J}\times\boldsymbol{\xi}^*\cdot\hat{\boldsymbol{Q}} - \varpi^*(\nabla\cdot\boldsymbol{\xi}) \\ - \varpi(\nabla\cdot\boldsymbol{\xi}^*) - \frac{1}{B^2+\gamma_s P}\left|\varpi - \boldsymbol{B}\cdot\hat{\boldsymbol{Q}} + \boldsymbol{\xi}\cdot\nabla P\right|^2. \tag{17}$$

It is easy to see that ϖ satisfies eq.(15).

If we put

$$\boldsymbol{\xi} = \frac{\xi_\psi\nabla\psi}{|\nabla\psi|^2} + \frac{\xi_s\boldsymbol{B}\times\nabla\psi}{B^2} + \xi_b\boldsymbol{B}, \tag{18}$$

and define the quantities

$$\sigma \equiv \frac{\boldsymbol{J}\cdot\boldsymbol{B}}{B^2}, \tag{19}$$

$$\hat{S} \equiv \frac{\nabla\psi\times\boldsymbol{B}}{|\nabla\psi|^2}\cdot\nabla\times\left(\frac{\nabla\psi\times\boldsymbol{B}}{|\nabla\psi|^2}\right), \tag{20}$$

$$K_\psi \equiv \frac{2\boldsymbol{\kappa}\cdot\nabla\psi}{|\nabla\psi|^2}, \quad K_s \equiv \frac{2\boldsymbol{\kappa}\cdot\boldsymbol{B}\times\nabla\psi}{B^2}, \tag{21}$$

$\boldsymbol{\kappa}$ being the curvature of the magnetic lines of force, the Lagrangian density can be written in the form

$$\mathcal{L}_{\rm I}[\boldsymbol{\xi},\varpi] \equiv \frac{q^2\rho}{|\nabla\psi|^2}|\xi_\psi|^2 + \frac{q^2\rho|\nabla\psi|^2}{B^2}|\xi_s|^2 + q^2\rho B^2|\xi_b|^2 + \frac{1}{|\nabla\psi|^2}|\boldsymbol{B}\cdot\nabla\xi_\psi|^2 \\ + \frac{|\nabla\psi|^2}{B^2}|\boldsymbol{B}\cdot\nabla\xi_s - \hat{S}\xi_\psi|^2 + \sigma\xi_\psi^*(\boldsymbol{B}\cdot\nabla\xi_s) + \sigma\xi_\psi(\boldsymbol{B}\cdot\nabla\xi_s^*) \\ - (P'K_\psi + \sigma\hat{S})|\xi_\psi|^2 + \frac{B^2\gamma_s P}{B^2+\gamma_s P}|\boldsymbol{K}\cdot\boldsymbol{\xi}_\perp - \boldsymbol{B}\cdot\nabla\xi_b|^2 \\ - \frac{|\varpi|^2}{B^2+\gamma_s P} - \frac{B^2\varpi^*}{B^2+\gamma_s P}\left[\boldsymbol{K}\cdot\boldsymbol{\xi}_\perp + \frac{\gamma_s P}{B^2}\boldsymbol{B}\cdot\nabla\xi_b\right] - \varpi^*\nabla\cdot\boldsymbol{\xi}_\perp \\ - \frac{B^2\varpi}{B^2+\gamma_s P}\left[\boldsymbol{K}\cdot\boldsymbol{\xi}_\perp + \frac{\gamma_s P}{B^2}\boldsymbol{B}\cdot\nabla\xi_b\right]^* - \varpi\nabla\cdot\boldsymbol{\xi}_\perp^*, \tag{22}$$

where $\boldsymbol{K}\cdot\boldsymbol{\xi}_\perp = K_\psi\xi_\psi + K_s\xi_s$, and

$$\nabla\cdot\boldsymbol{\xi}_\perp \equiv \nabla\cdot\left(\frac{\xi_\psi\nabla\psi}{|\nabla\psi|^2}\right) + \nabla\cdot\left(\frac{\xi_s\boldsymbol{B}\times\nabla\psi}{B^2}\right). \tag{23}$$

In writing eq.(22) the following relation is used.

$$\boldsymbol{B}\cdot\nabla\sigma = p'K_s. \tag{24}$$

The part of (22) containing ξ_s, and ξ_b

$$\mathcal{L}_{\rm con}[\xi_s,\xi_b] \equiv \frac{|\nabla\psi|^2}{B^2}\left\{q^2\rho|\xi_s|^2 + |\boldsymbol{B}\cdot\nabla\xi_s|^2\right\} \\ + q^2\rho B^2|\xi_b|^2 + \frac{B^2\gamma_s P}{B^2+\gamma_s P}|\boldsymbol{B}\cdot\nabla\xi_b - K_s\xi_s|^2, \tag{25}$$

is the Lagrangian[1] describing the continuous spectrum. The essentially same equations given in Ref.[1,5] can be derived from this Lagrangian; the difference is that the variable $\mathcal{D}$ is used in Ref.[1,5] instead of ξ_b,

$$\xi_b = \frac{\gamma_s P}{q^2 \rho} \boldsymbol{B} \cdot \nabla \mathcal{D}. \tag{26}$$

In addition to that, equations in [1,5] do not have Hermitian nature, while those derived from eq.(22) are naturally Hermitian.

Similarly, we obtain for the resistive case

$$\mathcal{L}_R = \mathcal{L}_0[\boldsymbol{\xi}_+, \varpi_+, \boldsymbol{a}_+] - \mathcal{L}_0[\boldsymbol{\xi}_-, \varpi_-, \boldsymbol{a}_-] + \mathcal{M}, \tag{27}$$

$$\begin{aligned} \mathcal{L}_0[\boldsymbol{\xi}, \varpi, \boldsymbol{a}] &= q^2 \rho |\boldsymbol{\xi}|^2 + \left| \hat{\boldsymbol{Q}} + \frac{1}{2} \boldsymbol{J} \times \boldsymbol{\xi} - \nabla \times (\eta \boldsymbol{a}) \right| - \frac{1}{4} |\boldsymbol{J} \times \boldsymbol{\xi}|^2 \\ &- \varpi^* (\nabla \cdot \boldsymbol{\xi}) - \varpi (\nabla \cdot \boldsymbol{\xi}^*) + q \eta |\boldsymbol{a}|^2 \\ &- \frac{1}{B^2 + \gamma_s P} \left| \boldsymbol{B} \cdot \hat{\boldsymbol{Q}} - \varpi - \boldsymbol{\xi} \cdot \nabla P - \boldsymbol{B} \cdot \nabla \times (\eta \boldsymbol{a}) \right|^2. \end{aligned} \tag{28}$$

The NOVA-R formulation[6] can be recovered by using the representation for the electric displacement

$$\boldsymbol{a} = A_\psi \nabla \psi + \frac{A_s \boldsymbol{B} \times \nabla \psi}{|\nabla \psi|^2} + A_b \boldsymbol{B}, \tag{29}$$

as well as eq.(18) for the plasma displacement. The boundary conditions in these variables are $\xi_\psi = A_s = A_b = 0$ on the boundary. The resulting expression is too cumbersome; therefore, we shall discuss only symbolically. We introduce the vectors

$$\boldsymbol{x} = (\xi_\psi, \varpi, \xi_s, \xi_b)^T, \quad \boldsymbol{y} = (A_\psi, A_s, A_b)^T, \tag{30}$$

where superscript T stands for the transposing, and write the Lagrangian in the form

$$\begin{aligned} \mathcal{L} &= (\boldsymbol{x}_+^T \cdot \mathbf{A} \cdot \boldsymbol{x}_+) + 2(\boldsymbol{x}_+^T \cdot \mathbf{B} \cdot \boldsymbol{y}_+) + (\boldsymbol{y}_+^T \cdot \mathbf{C} \cdot \boldsymbol{y}_+) + 2(\boldsymbol{x}_+^T \cdot \mathbf{D} \cdot \boldsymbol{y}_-) \\ &- (\boldsymbol{x}_-^T \cdot \mathbf{A} \cdot \boldsymbol{x}_-) - 2(\boldsymbol{x}_-^T \cdot \mathbf{B} \cdot \boldsymbol{y}_-) - (\boldsymbol{y}_-^T \cdot \mathbf{C} \cdot \boldsymbol{y}_-) - 2(\boldsymbol{x}_-^T \cdot \mathbf{D} \cdot \boldsymbol{y}_+), \end{aligned} \tag{31}$$

with operator matrices **A**, **B**, **C**, and **D**. Operator matrices **A** and **C** are symmetric

$$\mathbf{A}^T = \mathbf{A}, \quad \mathbf{C}^T = \mathbf{C}. \tag{32}$$

Especially, operator **A** is the one appearing in the ideal MHD. Note that the symmetry relation (32) does not mean Hermitian, since the eigenvalue q is complex. The derivative in ψ direction applies only for ξ_ψ, A_s, and A_b, for which the boundary conditions are specified. Then equations are written in the form

$$\left.\begin{aligned} \mathbf{A}\cdot x_+ + \mathbf{B}\cdot y_+ + \mathbf{D}\cdot y_- &= 0 \\ \mathbf{B}^T\cdot x_+ + \mathbf{C}\cdot y_+ - \mathbf{D}^T\cdot x_- &= 0 \\ \mathbf{A}\cdot x_- + \mathbf{B}\cdot y_- + \mathbf{D}\cdot y_+ &= 0 \\ \mathbf{B}^T\cdot x_- + \mathbf{C}\cdot y_- - \mathbf{D}^T\cdot x_+ &= 0 \end{aligned}\right\} \tag{33}$$

For the physical variables, we have

$$\left.\begin{aligned} \mathbf{A}\cdot x + (\mathbf{B}+\mathbf{D})\cdot y &= 0 \\ (\mathbf{B}^T - \mathbf{D}^T)\cdot x + \mathbf{C}\cdot y &= 0 \end{aligned}\right\}. \tag{34}$$

Thus, the symmetric and anti-symmetric operators appear in the cross term between **x** and **y**.

In the equilibrium such that any scalar quantity satisfies the symmetry relation $u(\theta,\phi) = u(-\theta,-\phi)$, i.e. Fourier expanded in cosine series with respect to θ and ϕ, variables are divided into two classes according their parity: one (C) is Fourier expanded in cosine series and the other (S) is expanded into sine series. The structure of the Lagrangian shows that the variables $(\xi_\psi, \varpi, A_s, A_b)$ have the same parity and the variables (A_ψ, ξ_s, ξ_b) have the other parity. However, this fact does not mean the quantities with same parity have the same phase, because Fourier coefficients are not real. The variables ϖ, ξ_s, ξ_b, and A_ψ can be eliminated algebraically from the Fourier expanded equations and the 3 second order differential equations for ξ_ψ, A_s, and A_b are obtained.

In conclusion, the use of the Lagrangian simplifies the calculation of the coefficients in the linearized MHD equations.

References

[1] C.Z.Chen and M.S.Chance: Phys. of Fluids 29 (1986) 3695.

[2] K.Appert, T.Gruber and J.Vaclavik: Phys. of Fluids 17 (1974) 1471.

[3] J.M.Greene, and J.L.Johnson: Plasma Phys. 10 (1968) 729.

[4] I.B.Bernstein, E.A.Frieman, M.D.Kruskal, and R.M.Kulsrud: Proc. Roy. Soc.(London) A244 (1958) 17.

[5] C.Z.Chen and M.S.Chance: J.Comp.Phys. 71 (1987) 124.

[6] T.R.Harley, C.Z.Chen,S.C.Jardin: PPPL-2737 (1991), submitted to J.Comp.Phys.

Recent Issues of NIFS Series

NIFS-102 N. Nakajima and M. Okamoto, *Rotations of Bulk Ions and Impurities in Non-Axisymmetric Toroidal Systems* ; July 1991

NIFS-103 A. J. Lichtenberg, K. Itoh, S. - I. Itoh and A. Fukuyama, *The Role of Stochasticity in Sawtooth Oscillation* ; Aug. 1991

NIFS-104 K. Yamazaki and T. Amano, *Plasma Transport Simulation Modeling for Helical Confinement Systems;* Aug. 1991

NIFS-105 T. Sato, T. Hayashi, K. Watanabe, R. Horiuchi, M. Tanaka, N. Sawairi and K. Kusano, *Role of Compressibility on Driven Magnetic Reconnection ;* Aug. 1991

NIFS-106 Qian Wen - Jia, Duan Yun - Bo, Wang Rong - Long and H. Narumi, *Electron Impact Excitation of Positive Ions - Partial Wave Approach in Coulomb - Eikonal Approximation* ; Sep. 1991

NIFS-107 S. Murakami and T. Sato, *Macroscale Particle Simulation of Externally Driven Magnetic Reconnection;* Sep. 1991

NIFS-108 Y. Ogawa, T. Amano, N. Nakajima, Y. Ohyabu, K. Yamazaki, S. P. Hirshman, W. I. van Rij and K. C. Shaing, *Neoclassical Transport Analysis in the Banana Regime on Large Helical Device (LHD) with the DKES Code;* Sep. 1991

NIFS-109 Y. Kondoh, *Thought Analysis on Relaxation and General Principle to Find Relaxed State;* Sep. 1991

NIFS-110 H. Yamada, K. Ida, H. Iguchi, K. Hanatani, S. Morita, O. Kaneko, H. C. Howe, S. P. Hirshman, D. K. Lee, H. Arimoto, M. Hosokawa, H. Idei, S. Kubo, K. Matsuoka, K. Nishimura, S. Okamura, Y. Takeiri, Y. Takita and C. Takahashi, *Shafranov Shift in Low-Aspect-Ratio Heliotron / Torsatron CHS* ; Sep 1991

NIFS-111 R. Horiuchi, M. Uchida and T. Sato, *Simulation Study of Stepwise Relaxation in a Spheromak Plasma ;* Oct. 1991

NIFS-112 M. Sasao, Y. Okabe, A. Fujisawa, H. Iguchi, J. Fujita, H. Yamaoka and M. Wada, *Development of Negative Heavy Ion Sources for Plasma Potential Measurement* ; Oct. 1991

NIFS-113 S. Kawata and H. Nakashima, *Tritium Content of a DT Pellet in Inertial Confinement Fusion* ; Oct. 1991

NIFS-114 M. Okamoto, N. Nakajima and H. Sugama, *Plasma Parameter Estimations for the Large Helical Device Based on the Gyro-*

Reduced Bohm Scaling ; Oct. 1991

NIFS-115 Y. Okabe, *Study of* Au^- *Production in a Plasma-Sputter Type Negative Ion Source* ; Oct. 1991

NIFS-116 M. Sakamoto, K. N. Sato, Y. Ogawa, K. Kawahata, S. Hirokura, S. Okajima, K. Adati, Y. Hamada, S. Hidekuma, K. Ida, Y. Kawasumi, M. Kojima, K. Masai, S. Morita, H. Takahashi, Y. Taniguchi, K. Toi and T. Tsuzuki, *Fast Cooling Phenomena with Ice Pellet Injection in the JIPP T-IIU Tokamak;* Oct. 1991

NIFS-117 K. Itoh, H. Sanuki and S. -I. Itoh, *Fast Ion Loss and Radial Electric Field in Wendelstein VII-A Stellarator*; Oct. 1991

NIFS-118 Y. Kondoh and Y. Hosaka, *Kernel Optimum Nearly-analytical Discretization (KOND) Method Applied to Parabolic Equations <<KOND-P Scheme>>;* Nov. 1991

NIFS-119 T. Yabe and T. Ishikawa, *Two- and Three-Dimensional Simulation Code for Radiation-Hydrodynamics in ICF*; Nov. 1991

NIFS-120 S. Kawata, M. Shiromoto and T. Teramoto, *Density-Carrying Particle Method for Fluid* ; Nov. 1991

NIFS-121 T. Ishikawa, P. Y. Wang, K. Wakui and T. Yabe, *A Method for the High-speed Generation of Random Numbers with Arbitrary Distributions;* Nov. 1991

NIFS-122 K. Yamazaki, H. Kaneko, Y. Taniguchi, O. Motojima and LHD Design *Group, Status of LHD Control System Design ; Dec. 1991*

NIFS-123 Y. Kondoh, *Relaxed State of Energy in Incompressible Fluid and Incompressible MHD Fluid* ; Dec. 1991

NIFS-124 K. Ida, S. Hidekuma, M. Kojima, Y. Miura, S. Tsuji, K. Hoshino, M. Mori, N. Suzuki, T. Yamauchi and JFT-2M Group, *Edge Poloidal Rotation Profiles of H-Mode Plasmas in the JFT-2M Tokamak ;* Dec. 1991

NIFS-125 H. Sugama and M. Wakatani, *Statistical Analysis of Anomalous Transport in Resistive Interchange Turbulence* ;Dec. 1991

NIFS-126 K. Narihara, *A Steady State Tokamak Operation by Use of Magnetic Monopoles* ; Dec. 1991

NIFS-127 K. Itoh, S. -I. Itoh and A. Fukuyama, *Energy Transport in the Steady*

State Plasma Sustained by DC Helicity Current Drive ;Jan. 1992

NIFS-128 Y. Hamada, Y. Kawasumi, K. Masai, H. Iguchi, A. Fujisawa, JIPP T-IIU Group and Y. Abe, *New Hight Voltage Parallel Plate Analyzer* ; Jan. 1992

NIFS-129 K. Ida and T. Kato, *Line-Emission Cross Sections for the Charge-exchange Reaction between Fully Stripped Carbon and Atomic Hydrogen in Tokamak Plasma*; Jan. 1992

NIFS-130 T. Hayashi, A. Takei and T. Sato, *Magnetic Surface Breaking in 3D MHD Equilibria of l=2 Heliotron* ; Jan. 1992

NIFS-131 K. Itoh, K. Ichiguchi and S. -I. Itoh, *Beta Limit of Resistive Plasma in Torsatron/Heliotron* ; Feb. 1992

NIFS-132 K. Sato and F. Miyawaki, *Formation of Presheath and Current-Free Double Layer in a Two-Electron-Temperature Plasma* ; Feb. 1992

NIFS-133 T. Maruyama and S. Kawata, *Superposed-Laser Electron Acceleration* Feb. 1992

NIFS-134 Y. Miura, F. Okano, N. Suzuki, M. Mori, K. Hoshino, H. Maeda, T. Takizuka, JFT-2M Group, S.-I. Itoh and K. Itoh, *Rapid Change of Hydrogen Neutral Energy Distribution at L/H-Transition in JFT-2M H-mode ;* Feb. 1992

NIFS-135 H. Ji, H. Toyama, A. Fujisawa, S. Shinohara and K. Miyamoto *Fluctuation and Edge Current Sustainment in a Reversed-Field-Pinch;* Feb. 1992

NIFS-136 K. Sato and F. Miyawaki, *Heat Flow of a Two-Electron-Temperature Plasma through the Sheath in the Presence of Electron Emission;* Mar. 1992

NIFS-137 T. Hayashi, U. Schwenn and E. Strumberger, *Field Line Diversion Properties of Finite β Helias Equilibria;* Mar. 1992

NIFS-138 T. Yamagishi, *Kinetic Approach to Long Wave Length Modes in Rotating Plasmas*; Mar. 1992

NIFS-139 K. Watanabe, N. Nakajima, M. Okamoto, Y. Nakamura and M. Wakatani, *Three-dimensional MHD Equilibrium in the Presence of Bootstrap Current for Large Helical Device (LHD)*; Mar. 1992

NIFS-140 K. Itoh, S. -I. Itoh and A. Fukuyama, *Theory of Anomalous Transport in Toroidal Helical Plasmas;* Mar. 1992

NIFS-141 Y. Kondoh, *Internal Structures of Self-Organized Relaxed States and Self-Similar Decay Phase;* Mar. 1992

NIFS-142 U. Furukane, K. Sato, K. Takiyama and T. Oda, *Recombining Processes in a Cooling Plasma by Mixing of Initially Heated Gas*; Mar. 1992

NIFS-143 Y. Hamada, K. Masai, Y. Kawasumi, H. Iguchi, A. Fijisawa and JIPP T-IIU Group, *New Method of Error Elimination in Potential Profile Measurement of Tokamak Plasmas by High Voltage Heavy Ion Beam Probes:* Apr. 1992

NIFS-144 N. Ohyabu, N. Noda, Hantao Ji, H. Akao, K. Akaishi, T. Ono, H. Kaneko, T. Kawamura, Y. Kubota, S. Morimoto. A. Sagara, T. Watanabe, K. Yamazaki and O. Motojima, *Helical Divertor in the Large Helical Device;* May 1992

NIFS-145 K. Ohkubo and K. Matsumoto, *Coupling to the Lower Hybrid Waves with the Multijunction Grill*; May 1992

NIFS-146 K. Itoh, S. -I.Itoh, A. Fukuyama, S. Tsuji and Allan J. Lichtenberg, *A Model of Major Disruption in Tokamaks*; May 1992

NIFS-147 S. Sasaki, S. Takamura, M. Ueda, H. Iguchi, J. Fujita and K. Kadota, *Edge Plasma Density Reconstruction for Fast Monoenergetic Lithium Beam Probing*; May 1992

NIFS-148 N. Nakajima, C. Z. Cheng and M. Okamoto, *High-n Helicity-induced Shear Alfvén Eigenmodes*; May 1992

NIFS-149 A. Ando, Y. Takeiri, O. Kaneko, Y. Oka, M. Wada, and T. Kuroda, *Production of Negative Hydrogen Ions in a Large Multicusp Ion Source with Double-Magnetic Filter Configuration*; May 1992

NIFS-150 N. Nakajima and M. Okamoto, *Effects of Fast Ions and an External Inductive Electric Field on the Neoclassical Parallel Flow, Current, and Rotation in General Toroidal Systems*; May 1992

NIFS-151 Y. Takeiri, A. Ando, O. Kaneko, Y. Oka and T. Kuroda, *Negative Ion Extraction Characteristics of a Large Negative Ion Source with Double-Magnetic Filter Configuration*; May 1992

NIFS-152 T. Tanabe, N. Noda and H. Nakamura, *Review of High Z Materials for PSI Applications* ; Jun. 1992

NIFS-153 Sergey V. Bazdenkov and T. Sato, *On a Ballistic Method for Double Layer Regeneration in a Vlasov-Poisson Plasma*; Jun. 1992