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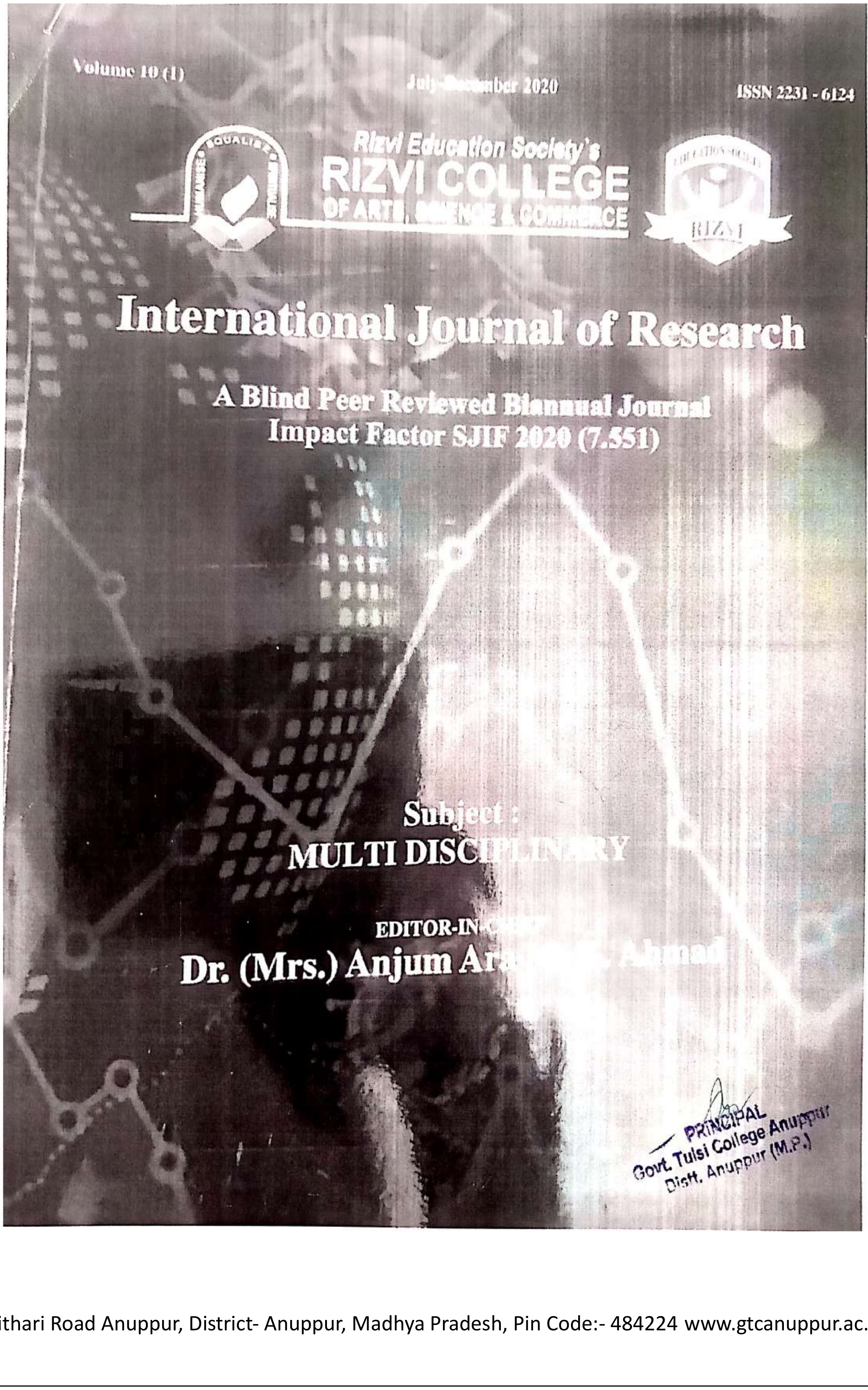

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On a Product Semi-Symmetric Non-Metric Connection in a Hyperbolic KÄhler Manifold

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Abstract
The object of the present paper is to characterize a type of product semi-symmetric non-metric connection in a hyperbolic Kähler manifold and to study some of its curvature properties.

AMS Subject Classification[2010]: *53C15, 53C55*

Keyword and Phrases: *Hyperbolic Kähler manifold, product semi-symmetric non-metric connection, projective curvature tensor, conformal curvature tensor, concircular curvature tensor, m-projective curvature tensor.*

Introduction

In 1924, A. Friedmann and J.A. Schouten [3] introduced the idea of semi-symmetric connection on differentiable manifold. In 1932, H.A. Hayden [5] studied semi-symmetric metric connection on a Riemannian manifolds. K.Yano [10] initiated systematic study of semi-symmetric metric connection and later on it was followed by several other geometers ([4], [2]). In 1975, S. Golab [4]defined and studied quarter-symmetric connection in manifolds with affine connection. K.Yano and T.Imai [11]studied semi-symmetric metric connection in complex manifold. M. Pravanovic' [8] extended the idea of semi-symmetric connection to product semi-symmetric connection in a locally decomposable Riemannian manifold and studied topics analogous to Yano and Imai [11]. R.N.Singh, M.K.Pandey and D.Gautam [9] have defined a type of product semi-symmetric non-metric connection in a locally decomposable Riemannian manifold and studied some of its curvature properties.

In this paper, we have defined a product semi-symmetric non-metric connection in a hyperbolic Kähler manifold and studied its curvature properties.

Preliminaries

Let M^n be a C^∞-complete real differentiable manifold of dimension n endowed with a real vector valued function F such that

$$\bar{\bar{X}} = X, \tag{2.1}$$

for arbitrary vector field X, where $\bar{X} = FX$.
If there exists pseudo Riemannian metric g such that

$$g(\bar{X},\bar{Y}) = -g(X,Y), \tag{2.2}$$

then M^n is called an almost hyperbolic Hermite manifold.
An almost hyperbolic Hermite manifold M^n is called a hyperbolic Kähler manifold if

$$\nabla_X F = 0, \tag{2.3}$$

where ∇ is the Riemannian connection.
The 2-form $'F$ defined by

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$$'F(X,Y) = g(\bar{X},Y), \quad (2.4)$$

satisfies

$$'F(X,\bar{Y}) = g(\bar{X},Y) = -g(X,\bar{Y}) = -'F(Y,X) \quad (2.5)$$

and

$$'F(\bar{X},\bar{Y}) = -'F(X,Y). \quad (2.6)$$

A linear connection ∇^* on (M^n, g) is termed as product semi-symmetric connection if its torsion tensor T^* has the form [8]

$$T^*(X,Y) = u(Y)X - u(X)Y + u(\bar{Y})\bar{X} - u(\bar{X})\bar{Y}, \quad (2.7)$$

where u is a non-zero 1-form associated with the vector field U on M^n by

$$u(X) = g(X,U) \quad (2.8)$$

and non-metric connection if

$$(\nabla^*_X g)(Y,Z) \neq 0. \quad (2.9)$$

A Product Semi-Symmetric Non-Metric Connection

Consider a connection ∇^* in a hyperbolic Kähler manifold M^n given by [9]

$$\nabla^*_X Y = \nabla_X Y + u(\bar{Y})\bar{X} + u(Y)X - g(X,Y)U, \quad (3.1)$$

where u is a non-zero 1-form associated with the vector field U defined by equation (2.8). From equation (3.1), it can be obtained that the torsion tensor

$$T^*(X,Y) = \nabla^*_X Y - \nabla^*_Y X - [X,Y] \quad (3.2)$$

of the connection ∇^* has the form

$$T^*(X,Y) = u(Y)X - u(X)Y + u(\bar{Y})\bar{X} - u(\bar{X})\bar{Y}, \quad (3.3)$$

which shows that the connection given by equation (3.1) is a product semi-symmetric connection. Also, we have

$$(\nabla^*_X g)(Y,Z) = X(g(Y,Z)) - g(\nabla^*_X Y, Z) - g(Y, \nabla^*_X Z), \quad (3.4)$$

which on using equations (2.4) and (3.1), gives

$$(\nabla^*_X g)(Y,Z) = -u(\bar{Y})'F(X,Z) - u(\bar{Z})'F(X,Y). \quad (3.5)$$

This shows that the connection under consideration is a non-metric one. Conversely it can be shown that a connection ∇^* satisfying equations (3.3) and (3.5) has the form given by the equation (3.1). Let $R^*(X,Y)Z$ be the curvature tensor of the hyperbolic Kähler manifold with respect to the product-semi-symmetric non-metric connection ∇^*. Then we have

$$R^*(X,Y)Z = \nabla^*_X \nabla^*_Y Z - \nabla^*_Y \nabla^*_X Z - \nabla^*_{[X,Y]} Z, \quad (3.6)$$

which on using equations (2.1), (2.3), (2.4), (2.5) and (3.1) in the above equation, we get

$$\begin{aligned} R^*(X,Y)Z &= R(X,Y)Z + \alpha(X,Z)Y - \alpha(Y,Z)X \\ &+ \alpha(X,\bar{Z})\bar{Y} - \alpha(Y,\bar{Z})\bar{X} - g(Y,Z)LX \\ &+ g(X,Z)LY + \{u(X)g(Y,Z) - u(Y)g(X,Z)\}U \\ &+ \{g(X,Z)Y - g(Y,Z)X\}u(U) \\ &+ \{u(Y)X - u(\bar{X})Y\}u(Z) + \{u(Y)\bar{X} \\ &- u(\bar{X})\bar{Y}\}u(Z) - 2u(\bar{Z})g(X,\bar{Y})U, \end{aligned} \quad (3.7)$$

where α is a tensor field of type (0, 2) given by

$$\alpha(X,Y) = (\nabla_X u)(Y) - u(X)u(Y) \quad (3.8)$$

and L is a tensor field of type (1, 1) given by

$$LX = \nabla_X U + u(\bar{U})\bar{X}. \quad (3.9)$$

If we put

$$'R^*(X,Y,Z,W) = g(R^*(X,Y)Z,W),$$

then in view of equation (3.7), above equation reduces to

$$\begin{aligned} 'R^*(X,Y,Z,W) &= 'R(X,Y,Z,W) + \alpha(X,Z)g(Y,W) \\ &- \alpha(Y,Z)g(X,W) + \alpha(X,\bar{Z})'F(Y,W) - \alpha(Y,\bar{Z})'F(X,W) \\ &- g(Y,Z)\beta(X,W) + g(X,Z)\beta(Y,W) \\ &+ u(W)\{u(X)g(Y,Z) - u(Y)g(X,Z)\} \\ &+ u(\bar{Z})\{u(\bar{Y})g(X,W) - u(\bar{X})g(Y,W)\} \\ &+ u(U)\{g(X,Z)g(Y,W) - g(Y,Z)g(X,W)\} \\ &+ u(Z)\{u(\bar{Y})'F(X,W) - u(\bar{X})'F(Y,W)\} \\ &- 2u(\bar{Z})u(W)'F(Y,\bar{X}), \end{aligned} \quad (3.10)$$

where $\beta(Y,Z)$ is a tensor of type (0, 2) given by

$$\beta(Y,Z) = g(LY,Z) = (\nabla_Y u)(Z) + u(\bar{U})'F(Y,Z). \quad (3.11)$$

Now, putting $X = W = e_i$ in equation (3.10) and summing over i, $1 \leq i \leq n$, we get

$$\begin{aligned} Ric^*(Y,Z) &= Ric(Y,Z) - (n-1)\alpha(Y,Z) + \alpha(\bar{Y},\bar{Z}) \\ &- \psi\alpha(Y,\bar{Z}) + \beta(Y,Z) - \delta g(Y,Z) \\ &- u(Y)u(Z) + (n-3)u(\bar{Y})u(\bar{Z}) + (\psi - 1)u(Z)u(\bar{Y}), \end{aligned} \quad (3.12)$$

where

$$\delta = b + (n-2)u(U) \quad (3.13)$$

and $\psi = \Sigma_{i=1}^n {'F}(e_i, e_i)$ and $b = \Sigma_{i=1}^n \beta(e_i, e_i)$ are the traces of the tensors 'F and β respectively.

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A Type of Product Semi-Symmetric Non-Metric Connection

We consider a product semi-symmetric non metric connection whose associated vector field U is recurrent with respect to Levi-Civita connection ∇ with u as a 1-form of recurrence i.e.

$$\nabla_X U = u(X)U \qquad (4.1)$$

and prove some results concerning such connection. Now, differentiating equation (2.8) and using equation (4.1), we obtain

$$(\nabla_X u)(Y) = u(X)u(Y), \qquad (4.2)$$

which on using equation (3.8), gives

$$a = 0. \qquad (4.3)$$

In this case tensors L and β reduces to

$$LX = u(X)U + u(\bar{U})\bar{X} \qquad (4.4)$$

and

$$\beta(Y,Z) = u(Y)u(Z) + u(\bar{U})'F(Y,Z). \qquad (4.5)$$

Therefore, using equations (4.3) and (4.4) in equation (3.7), we obtain

$$R^*(X,Y)Z = R(X,Y)Z + u(\bar{U})\{g(X,Z)\bar{Y} - g(Y,Z)\bar{X}\} + u(U)\{g(X,Z)Y - g(Y,Z)X\} + u(\bar{Z})\{u(\bar{Y})X - u(\bar{X})Y\} + u(Z)\{u(\bar{Y})\bar{X} - u(\bar{X})\bar{Y}\} - 2u(\bar{Z})g(X,\bar{Y})U, \qquad (4.6)$$

from which, we get

$$R^*(X,Y,Z,W) = R(X,Y,Z,W) + u(\bar{U})\{g(X,Z)'F(Y,W) - g(Y,Z)'F(X,W)\} + u(U)\{g(X,Z)g(Y,W) - g(Y,Z)g(X,W)\} + u(\bar{Z})\{u(\bar{Y})g(X,W) - u(\bar{X})g(Y,W)\} + u(Z)\{u(\bar{Y})'F(X,W) - u(\bar{X})'F(Y,W)\} - 2u(\bar{Z})g(X,\bar{Y})u(W). \qquad (4.7)$$

Putting $X = W = e_i$ in above equation and summing over i, $1 \le i \le n$, we get

$$Ric^*(Y,Z) = Ric(Y,Z) + u(\bar{U})'F(Y,Z) - \delta g(Y,Z) + (n-3)u(\bar{Y})u(\bar{Z}) + (\psi - 1)u(\bar{Y})u(Z), \qquad (4.8)$$

which gives

$$Q^*Y = QY + u(\bar{U})\bar{Y} - \delta Y - (n-3)u(\bar{Y})u(\bar{U}) + (\psi - 1)u(\bar{Y})\bar{U}. \qquad (4.9)$$

Further, putting $Y = Z = e_i$ in equation (4.8) and summing over i, $1 \le i \le n$, we get

$$r^* = r - \delta n - (n^2 - n - 3)u(U) + (2\psi - 1)u(\bar{U}), \qquad (4.10)$$

where r^* and r are the scalar curvatures of the hyperbolic Kähler manifold relative to the connections ∇^* and ∇ respectively.

Theorem 4.1 *In a hyperbolic Kähler manifold, torsion tensor of the product semi-symmetric non-metric connection is recurrent with respect to the Levi-Civita connection.*

Proof: Differentiating equation (3.3) with respect to Levi-Civita connection ∇ and using equation (4.2), we get

$$(\nabla_X T^*)(Y,Z) = u(X)T^*(Y,Z), \qquad (4.11)$$

which completes the theorem.

Theorem 4.2 *In a hyperbolic Kahler manifold the curvature tensor of the product semi-symmetric non-metric connection satisfies*

$$u(X)T^*(Y,Z) + u(Y)T^*(Z,X) + u(Z)T^*(X,Y), \qquad (4.14)$$

which on using equations (3.3) and (4.12) gives required result.

Projective Curvature Tensor of a Hyperbolic KÄhler Manifold with Connection ∇*.

Projective curvature tensor P of the manifold M^n is given by [6]

$$P(X,Y)Z = R(X,Y)Z - \frac{1}{(n-1)}[Ric(Y,Z)X - Ric(X,Z)Y]. \qquad (5.1)$$

Projective curvature tensor of a hyperbolic Kähler manifold admitting product semi-symmetric non-metric connection ∇* is given by

$$P^*(X,Y)Z = R^*(X,Y)Z - \frac{1}{(n-1)}[Ric^*(Y,Z)X - Ric^*(X,Z)Y], \qquad (5.2)$$

which on using equations (4.6) and (4.8), gives

$$P^*(X,Y)Z = P(X,Y)Z + u(\bar{U})\{g(X,Z)\bar{Y} - g(Y,Z)\bar{X}\} - \frac{1}{(n-1)}\{g(\bar{Y},Z)X - g(\bar{X},Z)Y\} + u(U)\{g(X,Z)Y - g(Y,Z)X\} + \frac{2}{(n-1)}u(\bar{Z})\{u(\bar{Y})X - u(\bar{X})Y\} + u(Z)\{u(\bar{Y})\bar{X} - u(\bar{X})\bar{Y}\} - \frac{\psi - 1}{(n-1)}u(Z)\{u(\bar{Y})X - u(\bar{X})Y\} - 2u(\bar{Z})g(X,\bar{Y})U \qquad (5.3)$$

Theorem 5.1 *A hyperbolic Kähler manifold with product semi-symmetric non-metric connection ∇* satisfies*

$$P^*(X,Y)Z + P^*(Y,X)Z = 0. \qquad (5.4)$$

Proof: Interchanging X and Y in equation (5.3) and using the fact that

$$P(X,Y)Z = -P(Y,X)Z,$$

we obtain the required result.

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Conformal Curvature Tensor of a Hyperbolic KÄhler Manifold with Connection ∇^*.

Conformal curvature tensor C of the manifold M^n is given by [6]

$$C(X,Y)Z = R(X,Y)Z - \frac{1}{(n-2)}[Ric(Y,Z)X - Ric(X,Z)Y + g(Y,Z)QX - g(X,Z)QY] + \frac{r}{(n-1)(n-2)}[g(Y,Z)X - g(X,Z)Y]. \quad (6.1)$$

Conformal curvature tensor of a hyperbolic Kähler manifold admitting product semi-symmetric non-metric connection ∇^* is given by

$$C^*(X,Y)Z = R^*(X,Y)Z - \frac{1}{(n-2)}[Ric^*(Y,Z)X - Ric^*(X,Z)Y + g(Y,Z)Q^*X - g(X,Z)Q^*Y] + \frac{r^*}{(n-1)(n-2)}[g(Y,Z)X - g(X,Z)Y]. \quad (6.2)$$

Now, using equations (4.6), (4.8), (4.9) and (4.10) in above equation, we get

$$\begin{aligned} C^*(X,Y)Z &= C(X,Y)Z + \frac{1}{n(-2)}u(\bar{U})\{g(\bar{X},Z)Y - g(\bar{Y},Z)X\} \\ &+ \frac{(n-1)}{(n-2)}u(\bar{U})\{g(X,Z)\bar{Y} - g(Y,Z)\bar{X}\} + u(Z)\{u(\bar{Y})\bar{X} \\ &- u(\bar{X})\bar{Y}\} - 2u(\bar{Z})g(X,\bar{Y})U - \frac{1}{(n-2)}\{u(\bar{\bar{X}})u(\bar{Z})Y \\ &- u(\bar{Y})u(\bar{Z})X\} + \frac{(n-3)}{(n-2)}\bar{U}\{u(\bar{X})g(Y,Z) - u(\bar{Y})g(X,Z)\} \\ &- \frac{2\delta(n-1)-(\psi+n-3)u(\bar{U})+(2n^2+5n-nb+\psi-1)u(U)}{(n-1)(n-2)} \times \\ &\{g(X,Z)Y - g(Y,Z)X\}. \end{aligned} \quad (6.3)$$

Theorem 6.1 *A hyperbolic Kähler manifold with product semi-symmetric non-metric connection* ∇^* *satisfies*

$$C^*(X,Y)Z + C^*(Y,X)Z = 0. \quad (6.4)$$

Proof: Interchanging X and Y in equation (6.3) and using the fact that $C(X,Y)Z = -C(Y,X)Z$, we obtain the required result.

Concircular Curvature Tensor of a Hyperbolic KÄhler Manifold with Connection ∇^*.

Concircular curvature tensor V of the manifold M^n is given by [6]

$$V(X,Y)Z = R(X,Y)Z - \frac{r}{n(n-1)}[g(Y,Z)X - g(X,Z)Y]. \quad (7.1)$$

Concircular curvature tensor of a hyperbolic Kähler manifold with product semi-symmetric non-metric connection ∇^* is given by

$$V^*(X,Y)Z = R^*(X,Y)Z - \frac{r^*}{n(n-1)}[g(Y,Z)X - g(X,Z)Y] \quad (7.2)$$

which on using equations (4.6) and (4.10), gives

$$\begin{aligned} V^*(X,Y)Z = &V(X,Y)Z + u(\bar{U})\{g(Y,Z)\bar{Y} - g(Y,Z)\bar{X}\} \\ &+ \frac{(n^2-n+1)}{n(n-1)}u(U)\{g(X,Z)Y - g(Y,Z)X\} \\ &+ u(Z)\{u(\bar{Y})\bar{X} - u(\bar{X})\bar{Y}\} \\ &+ u(\bar{Z})u(\bar{Y})X - u(\bar{X})Y - 2u(\bar{Z})g(X,\bar{Y})U \\ &- \frac{(\psi+n-3)u(\bar{U})-(n(n+b-2)-\psi)u(U)}{n(n-1)} \times \\ &\{g(Y,Z)X - g(X,Z)Y\} \end{aligned} \quad (7.3)$$

Theorem 7.1 *A hyperbolic Kähler manifold with product semi-symmetric non-metric connection* ∇^* *satisfies*

$$V^*(X,Y)Z + V^*(Y,X)Z = 0. \quad (7.4)$$

Proof: Interchanging X and Y in equation (7.3) and using the fact that $V(X,Y)Z = -V(Y,X)Z$, we obtain the required result.

m-Projective Curvature Tensor of a Hyperbolic KÄhler Manifold with Connection ∇^*.

In 1971, Pokhariyal and Mishra [7] defined a tensor field $\widetilde{W}$ on a Riemannian manifold M^n as

$$\widetilde{W}(X,Y)Z = R(X,Y)Z - \frac{1}{2(n-1)}[Ric(Y,Z)X - Ric(X,Z)Y + g(Y,Z)QX - g(X,Z)QY]. \quad (8.1)$$

for arbitrary vector fields X, Y and Z, where Ric is the Ricci tensor of type (0, 2), Q is the Ricci operator and ${}^{7}W(X,Y,Z,U) = g(\widetilde{W}(X,Y)Z,U)$. Such a tensor field is known as m-projective curvature tensor. m-projective curvature tensor of a hyperbolic Kähler manifold with product semi-symmetric non-metric connection ∇^* is given by

$$\widetilde{W}^*(X,Y)Z = R^*(X,Y)Z - \frac{1}{2(n-1)}[Ric^*(Y,Z)X - Ric^*(X,Z)Y + g(Y,Z)Q^*X - g(X,Z)Q^*Y]. \quad (8.2)$$

which on using equations (4.6) (4.8), (4.9)

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$$\tilde{W}^{*}(X,Y)Z = \tilde{W}(X,Y)Z + \frac{(2n-1)}{2(n-1)}u(\bar{U})\{g(X,Z)\bar{Y} - g(Y,Z)\bar{X}\} + u(U)\{g(X,Z)Y - g(Y,Z)X\}$$
$$- \frac{(n+1)}{2(n-1)}u(\bar{Z})\{u(\bar{X})Y - u(\bar{Y})X\}$$
$$- u(Z)\{u(\bar{X})\bar{Y} - u(\bar{Y})\bar{X}\} - 2u(\bar{Z})g(\bar{X},Y)U$$
$$+ \frac{1}{2(n-1)}u(\bar{U})\{g(\bar{X},Z)Y - g(\bar{Y},Z)X\}$$
$$- \frac{\delta}{(n-1)}\{g(X,Z)Y - g(Y,Z)X\}$$
$$+ \frac{(\psi-1)}{2(n-1)}u(Z)\{u(\bar{X})Y - u(\bar{Y})X\}$$
$$+ \frac{(n-3)}{2(n-1)}\bar{U}\{u(\bar{X})g(Y,Z) - u(\bar{Y})g(X,Z)\}$$
$$- \frac{(\psi-1)}{2(n-1)}U\{u(\bar{X})g(Y,Z) - u(\bar{Y})g(X,Z)\}. \tag{8.3}$$

Theorem 8.1 *A hyperbolic Kähler manifold with product semi-symmetric non-metric connection* ∇^{*} *satisfies*

$$\tilde{W}^{*}(X,Y)Z + \tilde{W}^{*}(Y,X)Z = 0. \tag{8.4}$$

Proof: Interchanging X and Y in equation (8.3) and using the fact that
$\tilde{W}(X,Y)Z = -\tilde{W}(Y,X)Z,$
we obtain the required result.

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