ON $\phi$-SYMMETRIC KENMOTSU MANIFOLDS WITH RESPECT TO QUARTER-SYMMETRIC METRIC CONNECTION

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Abstract. The object of the paper is to study $\phi$--symmetric Kenmotsu manifolds with respect to quarter-symmetric metric connection. We characterize locally $\phi$--symmetric, $\phi$--symmetric and locally concircular $\phi$--symmetric Kenmotsu manifolds with respect to quarter-symmetric metric connection and obtain interesting results.

1. Introduction

In 1924, A. Friedman and J.A. Schouten ([11, 19]) introduced the notion of a semi-symmetric linear connection on a differentiable manifold. H.A. Hayden [13] defined a metric connection with torsion on a Riemannian manifold. In 1970, K. Yano [26] studied some curvature and derivational conditions for semi-symmetric connections in Riemannian manifolds. In 1975, S. Golab [12] initiated the study of quarter-symmetric linear connection on a differentiable manifold. A linear connection $\tilde{\nabla}$ in an $n$-dimensional differentiable manifold is said to be a quarter-symmetric connection if its torsion tensor $T$ is of the form

$$T(X,Y) = \tilde{\nabla}_XY - \tilde{\nabla}_YX - [X,Y]$$

(1.1)

$$= \eta(Y)\phi X - \eta(X)\phi Y,$$

(1.2)

where $\eta$ is a 1-form and $\phi$ is a tensor of type $(1,1)$. In addition, a quarter-symmetric linear connection $\tilde{\nabla}$ satisfies the condition

$$\langle \tilde{\nabla}_X g \rangle(Y, Z) = 0$$

for all $X, Y, Z \in \chi(M)$, where $\chi(M)$ is the Lie algebra of vector fields of the manifold $M$, then $\tilde{\nabla}$ is said to be a quarter-symmetric metric connection. If we replace $\phi X$ by $X$ and $\phi Y$ by $Y$ in (1.2) then the connection is called a semi-symmetric metric connection [26]. In [22] M.M. Tripathi, [4] C.S. Bagewadi, D.G. Prakasha and Venkatesha, [8] U.C. De and G. Pathak studied semi-symmetric metric connection.

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in a Kenmotsu manifold. In [23, 24], M.M. Tripathi studied semi-symmetric non-metric connection in a Kenmotsu manifold. In 1980, R. S. Mishra and S. N. Pandey [15] studied quarter-symmetric metric connection and in particular, Ricci quarter-symmetric metric connection on Riemannian, Sasakian and Kaehlerian manifolds. Note that a quarter-symmetric metric connection is a Hayden connection with the torsion tensor of the form $(1, 2)$. Studies of various types of quarter-symmetric metric connection and their properties include ([10, 3, 15, 17, 18]) and [27] among others.

The notion of locally symmetry of Riemannian manifolds have been weakened by many authors in several ways to a different extent. As a weaker version of local symmetry, T. Takahashi [21] introduced the notion of locally $\phi-$symmetry on Sasakian manifolds. In the context of contact geometry the notion of $\phi-$symmetry is introduced and studied by E. Boeckx, P. Buecken and L. Vanhecke [7] with several examples. The notion of $\phi-$symmetry on Sasakian manifolds with respect to quarter-symmetric metric connection was studied in [16].

On the other hand K. Kenmotsu [14] defined a type of contact metric manifold which is now a days called Kenmotsu manifold. It may be mentioned that a Kenmotsu manifold is not a Sasakian manifold.

In the present paper, we study quarter-symmetric metric connection in a Kenmotsu manifold. The paper is organized as follows: In section 2, we give a brief account of Kenmotsu manifolds. In section 3 we give the relation between the Levi-Civita connection and the quarter-symmetric metric connection on a Kenmotsu manifold. In the next section, we characterize locally $\phi-$symmetric Kenmotsu manifold with respect to quarter-symmetric metric connection. In section 5, we study $\phi-$symmetric Kenmotsu manifolds with respect to quarter-symmetric metric connection. In section 6, we characterize locally concircular $\phi-$symmetric Kenmotsu manifolds with respect to quarter-symmetric metric connection.

2. Kenmotsu manifolds

An $n(= 2m+1)$-dimensional differentiable manifold $M$ is called an almost contact Riemannian manifold if either its structural group can be reduced to $U(n) \times 1$ or equivalently, there is an almost contact structure $(\phi, \xi, \eta)$ consisting of a $(1, 1)$ tensor field $\phi$, a vector field $\xi$ and a 1–form $\eta$ satisfying

\begin{align}
\phi^2 &= -I + \eta \otimes \xi \\
\eta(\xi) &= 1, \quad \phi \xi = 0, \quad \eta \circ \phi = 0.
\end{align}

Let $g$ be a compatible Riemannian metric with $(\phi, \xi, \eta)$, that is,

$$g(\phi X, \phi Y) = g(X, Y) - \eta(X)\eta(Y)$$

or equivalently,

$$g(X, \phi Y) = -g(\phi X, Y) \quad \text{and} \quad g(X, \xi) = \eta(X)$$

for any vector fields $X, Y$ on $M$ [6]. If, moreover

\begin{align}
(\nabla_X \phi)Y &= -\eta(Y)\phi X - g(X, \phi Y)\xi, \\
\nabla_X \xi &= X - \eta(X)\xi,
\end{align}

for any $X, Y \in \chi(M)$, then $(M, \phi, \xi, \eta, g)$ is called an almost Kenmotsu manifold. Here $\nabla$ denotes the Riemannian connection of $g$. 
An almost Kenmotsu manifold become a Kenmotsu manifold if
\[ g(X, \phi Y) = d\eta(X, Y) \] for all vector fields \( X, Y \).

In a Kenmotsu manifold \( M \) the following relations hold [14]:
\[ (\nabla_X \eta)Y = g(X, Y) - \eta(X)\eta(Y), \]
\[ R(X, Y)\xi = \eta(X)Y - \eta(Y)X, \]
\[ S(X, \xi) = -(n - 1)\eta(X), \]
for every vector fields \( X, Y, Z \) on \( M \) where \( R \) and \( S \) are the Riemannian curvature tensor and the Ricci tensor with respect to Levi-Civita connection, respectively.

**Definition 2.1.** A Kenmotsu manifold \( M \) is said to be locally \( \phi \)-symmetric if
\[ \phi^2((\nabla_W R)(X, Y)Z) = 0, \]
for all vector fields \( X, Y, Z, W \) orthogonal to \( \xi \). This notion was introduced by T. Takahashi for Sasakian manifolds.

**Definition 2.2.** A Kenmotsu manifold \( M \) is said to be \( \phi \)-symmetric if
\[ \phi^2((\nabla_W R)(X, Y)Z) = 0, \]
for arbitrary vector fields \( X, Y, Z, W \).

**Definition 2.3.** A Kenmotsu manifold \( M \) is said to be locally concircular \( \phi \)-symmetric if
\[ \phi^2((\nabla_W \tilde{C})(X, Y)Z) = 0, \]
for all vector fields \( X, Y, Z, W \) orthogonal to \( \xi \), where \( \tilde{C} \) is the concircular curvature tensor given by [25]
\[ \tilde{C}(X, Y)Z = R(X, Y)Z - \frac{r}{n(n - 1)}[g(Y, Z)X - g(X, Z)Y]. \]
Here \( R \) and \( r \) are the Riemannian curvature tensor and scalar curvature tensor, respectively.

3. Relation between the Levi-Civita connection and the quarter-symmetric metric connection in a Kenmotsu manifolds

Let \( \tilde{\nabla} \) be a linear connection and \( \nabla \) be a Riemannian connection of an almost contact metric manifold \( M \) such that
\[ \tilde{\nabla}_X Y = \nabla_X Y + H(X, Y), \]
where \( H \) is a tensor of type \((1, 1)\). For \( \tilde{\nabla} \) to be a quarter-symmetric metric connection in \( M \), we have [12]
\[ H(X, Y) = \frac{1}{2}[T(X, Y) + T'(X, Y) + T'(Y, X)] \]
and
\[ g(T'(X, Y), Z) = g(T(Z, X), Y). \]
From (1.1) and (3.3) we get
\[ T'(X, Y) = g(\phi Y, X)\xi - \eta(X)\phi Y. \]
Using (1.1) and (3.4) in (3.2) we obtain

\[ H(X, Y) = -\eta(X)\phi Y. \]

Hence a quarter-symmetric metric connection \( \tilde{\nabla} \) in a Kenmotsu manifold is given by

\[ (3.5) \quad \tilde{\nabla}_X Y = \nabla_X Y - \eta(X)\phi Y. \]

Therefore equation (3.5) is the relation between the Levi-Civita connection and the quarter-symmetric metric connection on a Kenmotsu manifold.

A relation between the curvature tensor of \( M \) with respect to the quarter-symmetric metric connection \( \tilde{\nabla} \) and the Levi-Civita connection \( \nabla \) is given by [20]

\[ \tilde{R}(X, Y) Z = R(X, Y) Z - 2d\eta(X, Y) \phi Z + [\eta(X) g(\phi Y, Z) - \eta(Y) g(\phi X, Z)]\xi + [\eta(Y) \phi X - \eta(X) \phi Y] \eta(Z). \]

(3.6)

where \( \tilde{R} \) and \( R \) are the Riemannian curvatures of the connection \( \tilde{\nabla} \) and \( \nabla \), respectively. From (3.6), it follows that

\[ \tilde{S}(Y, Z) = S(Y, Z) - 2d\eta(\phi Z, Y) + g(\phi Y, Z) + \psi \eta(Y) \eta(Z), \]

where \( \tilde{S} \) and \( S \) are the Ricci tensors of the connection \( \tilde{\nabla} \) and \( \nabla \), respectively and \( \psi = \sum_{i=1}^{n} g(\phi e_i, e_i) = \text{Trace of } \phi \). From (3.7) it is clear that in a Kenmotsu manifold the Ricci tensor with respect to the quarter-symmetric metric connection is not symmetric. Contracting (3.7), we get

\[ \tilde{r} = r + 2(n - 1), \]

where \( \tilde{r} \) and \( r \) are the scalar curvatures of the connection \( \tilde{\nabla} \) and \( \nabla \), respectively.

4. Locally \( \phi \)-symmetric Kenmotsu manifolds with respect to the quarter-symmetric metric connection

Analogous to the definition of locally \( \phi \)-symmetric Kenmotsu manifolds with respect to Levi-Civita connection, we define a locally \( \phi \)-symmetric Kenmotsu manifold with respect to the quarter-symmetric metric connection by

\[ \phi^2((\nabla_W \tilde{R})(X, Y) Z) = 0 \]

for all vector fields \( X, Y, Z, W \) orthogonal to \( \xi \).

Using (3.5) we can write

\[ (\tilde{\nabla}_W \tilde{R})(X, Y) Z = (\nabla_W \tilde{R})(X, Y) Z - \eta(W)\phi \tilde{R}(X, Y) Z. \]

Now differentiating (3.6) with respect to \( W \), we obtain

\[ (\nabla_W \tilde{R})(X, Y) Z = (\nabla_W R)(X, Y) Z - 2d\eta(X, Y)(\nabla_W \phi)Z + \{(\nabla_W \eta)(X) g(\phi Y, Z) - \eta(X) g(\phi X, Z)\eta(Y)\}(\nabla_W \xi) + \{\eta(Y) \phi X - \eta(X) \phi Y\}(\nabla_W \eta)(Z) + \{(\nabla_W \eta)(\phi Y)(\nabla_W \phi)(X) - \eta(X) \phi Y - \eta(X)(\nabla_W \phi)(Y)\} \eta(Z). \]

(4.3)
Using (2.3) and (2.6), in (4.3) we get
\[(\nabla_W \tilde{R})(X, Y) Z = (\nabla_W R)(X, Y) Z - 2\eta(X, Y) \{g(\phi W, Z) \xi - \eta(Z) \phi W\} + \{g(X, W) g(\phi Y, Z) - g(Y, W) g(\phi X, Z)\} \xi \]
\[-2\{\eta(X) \eta(W) g(\phi Y, Z) - \eta(Y) \eta(W) g(\phi X, Z)\} \xi + \{g(\phi Y, Z) \eta(X) - g(\phi X, Z) \eta(Y)\}\{W\} + \{g(W, Z) - \eta(W) \eta(Z)\} \times \{\eta(Y) \phi X - \eta(X) \phi Y\} + \{g(Y, W) \phi X - g(X, W) \phi Y\} \eta(Y) \phi X
g\eta(W) \phi Y - 2\eta(X) \eta(Y) \phi W) \eta(Z).

With the help of (2.2) and (4.4), in (4.2) we obtain
\[\phi^2(\tilde{\nabla}_W \tilde{R})(X, Y) Z = \phi^2(\nabla_W R)(X, Y) Z - 2d\eta(X, Y) \eta(Z) \phi W + \{g(\phi Y, Z) \eta(X) - g(\phi X, Z) \eta(Y)\}\{W\} + \{g(W, Z) - \eta(W) \eta(Z)\} \{\eta(Y) \phi^2(\phi X) - \eta(X) \phi^2(\phi Y)\} - g((\tilde{\nabla}_W \tilde{R})(X, Y) Z \eta(Z) - \eta(W) \phi^2(\phi W) \eta(Z).
\]
(4.5)

If we consider \(X, Y, Z, W\) orthogonal to \(\xi\), (4.5) reduces to
\[\phi^2((\tilde{\nabla}_W \tilde{R})(X, Y) Z = \phi^2((\nabla_W R)(X, Y) Z).\]

Hence we can state the following:

**Theorem 4.1.** For a Kenmotsu manifold the quarter-symmetric metric connection \(\tilde{\nabla}\) is locally \(\phi\)–symmetric if and only if the Levi-Civita connection \(\nabla\) is so.

5. \(\phi\)–symmetric Kenmotsu manifolds with respect to the quarter-symmetric metric connection

A Kenmotsu manifold \(M\) is said to be \(\phi\)-symmetric with respect to quarter-symmetric metric connection if
\[\phi^2((\tilde{\nabla}_W \tilde{R})(X, Y) Z = 0\]

for arbitrary vector fields \(X, Y, Z, W\).

Let us consider a \(\phi\)–symmetric Kenmotsu manifolds with respect to quarter-symmetric metric connection. Then by virtue of (2.1) and (5.1) we have
\[-g((\tilde{\nabla}_W \tilde{R})(X, Y) Z + \eta((\tilde{\nabla}_W \tilde{R})(X, Y) Z) \xi = 0,\]
from which it follows
\[g((\tilde{\nabla}_W \tilde{R})(X, Y) Z, U) + \eta((\tilde{\nabla}_W \tilde{R})(X, Y) Z) g(\xi, U) = 0.\]
Let \(\{e_i\}\) \(i = 1, 2, ..., n\), be an orthonormal basis of the tangent space at any point of the manifold. Then putting \(X = U = e_i\) in (5.3) and taking summation over \(i\), \(1 \leq i \leq n\), we get
\[g((\tilde{\nabla}_W \tilde{S})(Y, Z) + \sum_{i=1}^{n} \eta((\tilde{\nabla}_W \tilde{R})(e_i, Y) Z) \eta(e_i) = 0.\]

The second term of (5.4) by putting \(Z = \xi\) takes the form
\[\eta((\tilde{\nabla}_W \tilde{R})(e_i, Y) \xi) \eta(e_i) = g((\tilde{\nabla}_W \tilde{R})(e_i, Y) \xi, \xi) g(e_i, \xi),\]
(5.5)
which is denoted by $E$. In this case $E$ vanishes. Since by using (3.5), we can write
\begin{equation}
(5.6) \quad g((\nabla W R)(e_i, Y)\xi, \xi) = g((\nabla W \tilde{R})(e_i, Y)\xi, \xi) - \eta(W)\eta(\phi \tilde{R}(e_i, Y)\xi)
\end{equation}
By (2.2) and (4.4), we obtain from (5.6)
\begin{equation}
(5.7) \quad g((\nabla W \tilde{R})(e_i, Y)\xi, \xi) = 0.
\end{equation}
By replacing $Z$ by $\xi$ in (5.4) and using (5.8), we get
\begin{equation}
(5.9) \quad (\nabla W \tilde{S})(Y, \xi) = 0.
\end{equation}
We know that
\begin{equation}
(5.10) \quad (\nabla W \tilde{S})(Y, \xi) = -\tilde{R}(Y, W) + 2d\eta(\phi Y, W) - g(\phi Y, W)
\end{equation}
\begin{equation}
+ \{\psi - (n - 1)\}g(Y, W) - \psi\eta(Y)\eta(W).
\end{equation}
Applying (5.11) in (5.9), we obtain
\begin{equation}
(5.12) \quad -\tilde{R}(Y, W) + 2d\eta(\phi Y, W) - g(\phi Y, W) + \{\psi - (n - 1)\}g(Y, W) - \psi\eta(Y)\eta(W) = 0.
\end{equation}
Then contracting the last equation, one can get
\begin{equation}
(5.13) \quad r = -n(n - 1).
\end{equation}
This leads to the following:

**Theorem 5.1.** Let $M$ be a $\phi$-symmetric Kenmotsu manifolds with respect to quarter-symmetric metric connection $\nabla$. Then the manifold has a constant negative scalar curvature $r$ with respect to Levi-Civita connection $\nabla$ of $M$ given by (5.13).

6. **Locally concircular $\phi$–symmetric Kenmotsu manifolds with respect to the quarter-symmetric metric connection**

A Kenmotsu manifold $M$ is said to be a locally concircular $\phi$–symmetric with respect to quarter-symmetric metric connection if
\begin{equation}
(6.1) \quad \phi^2((\nabla W \tilde{C})(X, Y)Z) = 0
\end{equation}
for all vector fields $X, Y, Z, W$ orthogonal to $\xi$, where $\tilde{C}$ is the concircular curvature tensor with respect to quarter-symmetric metric connection given by
\begin{equation}
(6.2) \quad \tilde{C}(X, Y)Z = \tilde{R}(X, Y)Z - \frac{\tilde{r}}{n(n - 1)}[g(Y, Z)X - g(X, Z)Y].
\end{equation}
where $\tilde{R}$ and $\tilde{r}$ are the Riemannian curvature tensor and scalar curvature with respect to quarter-symmetric metric connection $\nabla$, respectively. Using (3.5) we can write
\begin{equation}
(6.3) \quad (\nabla W \tilde{C})(X, Y)Z = (\nabla W \tilde{C})(X, Y)Z - \eta(W)\phi \tilde{C}(X, Y)Z.
\end{equation}
Now differentiating (6.2) with respect to $W$, we obtain

\begin{equation}
(\nabla_W \tilde{C})(X, Y) Z = (\nabla_W \tilde{R})(X, Y) Z - \frac{(\nabla_W \tilde{F})}{n(n-1)} [g(Y, Z) X - g(X, Z) Y].
\end{equation}

By making use of (4.4) and (3.8) in (6.4), we have

\begin{align}
(\nabla_W \tilde{C})(X, Y) Z &= (\nabla_W R)(X, Y) Z - 2d\eta(X, Y) \{ g(\phi W, Z) \xi - \eta(Z) \phi W \} \\
&\quad + \{ g(X, W) h(\phi Y, Z) - g(Y, W) g(\phi X, Z) \} \xi \\
&\quad - 2\{ \eta(X) \eta(W) g(\phi Y, Z) - \eta(Y) \eta(W) g(\phi X, Z) \} \xi \\
&\quad + \{ g(\phi Y, Z) \eta(X) - g(\phi X, Z) \eta(Y) \} (W) + \{ g(W, Z) - \eta(W) \eta(Z) \} \\
&\times \{ \eta(Y) \phi X - \eta(X) \phi Y \} + \{ g(Y, W) \phi X - g(X, W) \phi Y \} \\
&\quad + g(\phi W, X) \eta(Y) \xi - g(\phi W, Y) \eta(X) \xi - \eta(Y) \eta(W) \phi X \\
&\quad - \eta(X) \eta(W) \phi Y - 2\eta(X) \eta(Y) \phi W \} \eta(Z) \\
\end{align}

(6.5)

Taking account of (2.12), we write (6.5) as

\begin{align}
(\nabla_W \tilde{C})(X, Y) Z &= (\nabla_W \tilde{C})(X, Y) Z - 2d\eta(X, Y) \{ g(\phi W, Z) \xi - \eta(Z) \phi W \} \\
&\quad + \{ g(X, W) g(\phi Y, Z) - g(Y, W) g(\phi X, Z) \} \xi \\
&\quad - 2\{ \eta(X) \eta(W) g(\phi Y, Z) - \eta(Y) \eta(W) g(\phi X, Z) \} \xi \\
&\quad + \{ g(\phi Y, Z) \eta(X) - g(\phi X, Z) \eta(Y) \} (W) + \{ g(W, Z) - \eta(W) \eta(Z) \} \\
&\times \{ \eta(Y) \phi X - \eta(X) \phi Y \} + \{ g(Y, W) \phi X - g(X, W) \phi Y \} \\
&\quad + g(\phi W, X) \eta(Y) \xi - g(\phi W, Y) \eta(X) \xi - \eta(Y) \eta(W) \phi X \\
&\quad - \eta(X) \eta(W) \phi Y - 2\eta(X) \eta(Y) \phi W \} \eta(Z). \\
\end{align}

(6.6)

Applying (2.2) and (6.6), in (6.3) we have

\begin{align}
\phi^2(\nabla_W \tilde{C})(X, Y) Z &= \phi^2(\nabla_W \tilde{C})(X, Y) Z + 2d\eta(X, Y) \eta(Z) \phi^2(\phi W) \\
&\quad + \{ g(\phi Y, Z) \eta(X) - g(\phi X, Z) \eta(Y) \} \phi^2(\phi W) \\
&\quad + \{ g(W, Z) - \eta(W) \eta(Z) \} \times \{ \eta(Y) \phi X - \eta(X) \phi Y \} \\
&\quad + \{ g(Y, W) \phi^2(\phi X) - g(X, W) \phi^2(\phi Y) - \eta(Y) \eta(W) \phi^2(\phi X) \\
&\quad - \eta(X) \eta(W) \phi^2(\phi Y) - 2\eta(X) \eta(Y) \phi^2(\phi W) \} \eta(Z) \\
&\quad - \eta(W) \phi^2(\phi \tilde{C})(X, Y) Z. \\
\end{align}

(6.7)

If we consider $X, Y, Z, W$ orthogonal to $\xi$, (6.7) reduces to

\[ \phi^2(\nabla_W \tilde{C})(X, Y) Z = \phi^2(\nabla_W \tilde{C})(X, Y) Z. \]

Hence we have the following:

**Theorem 6.1.** For a Kenmotsu manifold the quarter-symmetric metric connection $\tilde{\nabla}$ is locally concircular $\phi$-symmetric if and only if the Levi-Civita connection $\nabla$ is so.
Next, from (2.2) and (6.5) in (6.3), we have
\[
\phi^2(\nabla W \tilde{\phi})(X,Y)Z = \phi^2(\nabla W R)(X,Y)Z + 2d\eta(X,Y)\eta(Z) \phi^2(\phi W) + \{g(\phi Y,Z)\eta(X) - g(\phi X,Z)\eta(Y)\} \phi^2(W) + \{g(W,Z) - \eta(W)\eta(Z)\} \times \{\eta(Y)\phi^2(X) - \eta(X)\phi^2(\phi Y)\} + \{g(Y,W)\phi^2(\phi X) - g(X,W)\phi^2(\phi Y) - \eta(Y)\eta(W)\phi^2(\phi X) - \eta(X)\eta(W)\phi^2(\phi Y) - 2\eta(X)\eta(Y)\phi^2(\phi W)\}\eta(Z) - \eta(Y)\phi^2(\phi \tilde{\phi})(X,Y)Z + \frac{\nabla W r}{n(n - 1)}[g(Y,Z)\phi^2X - g(X,Z)\phi^2Y]
\]
(6.8)
\[-\eta(W)\phi^2(\phi \tilde{\phi})(X,Y)Z.
\]
If we take \(X, Y, Z, W\) orthogonal to \(\xi\), (6.8) reduces to
\[
\phi^2(\nabla W \tilde{\phi})(X,Y)Z = \phi^2(\nabla W R)(X,Y)Z - \frac{\nabla W r}{n(n - 1)}[g(Y,Z)\phi^2X - g(X,Z)\phi^2Y].
\]
If \(r\) is constant, then \(\nabla W r\) is zero. Therefore, (6.9) yields
\[
\phi^2(\nabla W \tilde{\phi})(X,Y)Z = \phi^2(\nabla W R)(X,Y)Z.
\]
Thus, we can state the following:

**Theorem 6.2.** Let \(M\) be an locally concircular \(\phi\)-symmetric Kenmotsu manifold with respect to quarter-symmetric metric connection \(\nabla\). If the scalar curvature \(r\) with respect to Levi-Civita connection is constant, then \(M\) is locally \(\phi\)-symmetric with respect to Levi-Civita connection \(\nabla\).

**References**


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