Konuralp Journal of Mathematics, 9 (2) (2021) 332-336

Konuralp Journal of Mathematics

Research Paper

https://dergipark.org.tr/en/pub/konuralpjournalmath

e-ISSN: 2147-625X

On The Non-Existence of Weakly Symmetric Nearly Kenmotsu Manifold with Semi-Symmetric Metric Connection

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Abstract

The object of this paper is to study the non-existence of weakly symmetric nearly Kenmotsu manifold with semi-symmetric metric connection.

Keywords: *Nearly Kenmotsu manifold,weakly symmetric manifold, semi-symmetric metric connection.*
2010 Mathematics Subject Classification: *53C21, 53C25*

1. Introduction

In 1989, L. Tamassy and T. Q. Binh introduced the notions of weakly symmetric and weakly Ricci-symmetric manifolds [13].
A non flat differentiable manifold M^{2n+1} is called weakly symmetric if there exist a vector field P and $1-$forms α, β, γ, δ on M^{2n+1} such that

$$(\nabla_X R)(Y,Z)V=\alpha(X)R(Y,Z)V+\beta(Y)R(X,Z)V+\gamma(Z)R(Y,X)V+\delta(V)R(Y,Z)X+g(R(Y,Z)V,X)P, \tag{1.1}$$

holds for all vector fields $X,Y,Z,V\in\chi(M^{2n+1})$ ([1], [13], [14]). A weakly symmetric manifold (M^{2n+1},g) is pseudo symmetric if $\beta=\gamma=\delta=\frac{1}{2}\alpha$ and $P=A$, locally symmetric if $\alpha=\beta=\gamma=\delta=0$ and $P=0$. A weakly symmetric manifold is said to be proper if at least one of the 1-forms α, β, γ and δ is not zero or $P\neq 0$ holds for all vector fields $X,Y,Z\in\chi(M^{2n+1})$.
A non-flat differentiable manifold M^{2n+1} is called weakly Ricci-symmetric if there exist 1-forms ρ, μ, υ such that the condition

$$(\nabla_X S)(Y,Z)=\rho(X)S(Y,Z)+\mu(Y)S(X,Z)+\upsilon(Z)S(X,Y),$$

holds for all vector fields X,Y,Z $\chi(M^{2n+1})$. İf $\rho=\mu=\upsilon$ then M^{2n+1} is called pseudo Ricci-symmetric. If M^{2n+1} is weakly symmetric, from (1.1), we have

$$(\nabla_X S)(Z,V)=\alpha(X)S(Z,V)+\beta(R(X,Z)V+\gamma(Z)S(X,V)+\delta(V)S(X,Z)+p(R(X,V)Z) \tag{1.2}$$

where p is defined by $p(X)=g(X,P)$ for all $X\in\chi(M^{2n+1})$ ([11], [13]). On the other hand, the notion of a semi-symmetric connection on a differentiable manifold were introduced in [8]. A linear connection ∇ is called a semi-symmetric connection if it is not torsion free and satisfies the expression $T(X,Y)=\eta(Y)X-\eta(X)Y$. It is known that if $\nabla g=0$, then the connection which satisfies the semi-symmetric condition, is called semi-symmetric metric connection, otherwise it is non-metric [12]. Hayden and Yano improved this concept and obtained several important results in Riemannian manifolds ([9], [15]). In recent years, there have been many studies on weakly symmetric and semi-symmetric metric connection ([1], [2], [5], [6]).
In this paper we have investigated weakly symmetric nearly Kenmotsu manifolds with respect to the semi-symmetric metric connection. Firstly we give some brief information about the nearly Kenmotsu manifolds admitting semi-symmetric metric connection. Then we obtain necessary conditions of the non-existence of weakly symmetric nearly Kenmotsu manifold with semi-symmetric metric connection.

2. Preliminaries

An $n-$dimensional differentiable manifold M^{2n+1} is called an almost contact Riemannian manifold if there is an almost contact structure (φ,ξ,η)consisting of a $(1,1)$ tensor field φ, a vector field ξ and $1-$form satisfying

$$\eta(\xi)=1 \quad \varphi\xi=0, \tag{2.1}$$

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$$\varphi^2 X = -X + \eta(X)\xi, \tag{2.2}$$

Let g be the Riemannian metric with the almost contact structure, that is

$$\begin{aligned} g(\varphi X, \varphi Y) &= g(X,Y) - \eta(X)\eta(Y), \\ \eta(X) &= g(X,\xi), \end{aligned} \tag{2.3}$$

for any vector fields X,Y on M^{2n+1}, then the manifold is said to be almost contact metric manifold ([7]). If moreover

$$(\nabla_X \varphi)Y = -g(X,\varphi Y)\xi - \eta(Y)\varphi X, \nabla_X \xi = X - \eta(X)\xi, \tag{2.4}$$

where ∇ denotes the Riemannian connection of g, then $(M^{2n+1},\varphi,\xi,\eta,g)$ is called a Kenmotsu manifold [10]. An almost contact manifold $(M^{2n+1},\varphi,\xi,\eta,g)$ is called nearly Kenmotsu manifold by with the following relation ([3], [4]):

$$\eta(R(X,Y)Z) = g(X,Z)\eta(Y) - g(Y,Z)\eta(X), \tag{2.5}$$

$$R(\xi,X)Y = -g(Y,X)\xi + \eta(X)Y, \tag{2.6}$$

$$R(X,Y)\xi = \eta(X)Y - \eta(Y)X, \tag{2.7}$$

$$S(X,\xi) = -2n\eta(X),\ Q\eta = -2n\xi, \tag{2.8}$$

$$S(\phi X,\phi Y) = S(X,Y) + 2n\eta(X)\eta(Y), \tag{2.9}$$

for all vector fields X,Y,Z in which R denotes the Riemannian curvature tensor and S denotes the Ricci tensor.

Definition 2.1. *Let M^{2n+1} be an $(2n+1)$-dimensional nearly Kenmotsu manifold. A connection $\tilde{\nabla}$ in M^{2n+1} is called semi-symmetric connection if its torsion tensör [12]*

$$T(X,Y) = \tilde{\nabla}_X Y - \tilde{\nabla}_Y X - [X,Y], \tag{2.10}$$

satisfies

$$T(X,Y) = \eta(Y)X - \eta(X)Y. \tag{2.11}$$

Further, a semi-symmetric connection is called semi-symmetric metric connection if

$$(\tilde{\nabla}_X\ g)(Y,Z) = g(\tilde{\nabla}_X Y,Z) + g(Y,\tilde{\nabla}_X Z). \tag{2.12}$$

On a $(2n+1)-$dimensional nearly Kenmotsu manifold with semi-symmetric metric connection some basic curvature properties as follows [12]:

$$\tilde{R}(X,Y)Z = R(X,Y)Z + 3[g(X,Z)Y - g(Y,Z)X] + 2[g(X,Y)\eta(X) - g(X,Z)\eta(Y)]\xi + 2[\eta(Y)X - \eta(X)Y]\eta(Z), \tag{2.13}$$

$$\tilde{S}(Y,Z) = S(Y,Z) + (2-6n)g(Y,Z) + 2(2n-1)\eta(Y)\eta(Z), \tag{2.14}$$

$$\tilde{S}(Y,\xi) = -4n\eta(Y), \tag{2.15}$$

$$\tilde{R}(X,Y)\xi = 2[\eta(X)Y - \eta(Y)X], \tag{2.16}$$

$$\tilde{R}(\xi,Y)Z = 2[-g(Y,Z)\xi + \eta(Z)Y], \tag{2.17}$$

$$\tilde{R}(X,Y)Z = -\tilde{R}(Y,X)Z, \tag{2.18}$$

$$\tilde{Q}Y = -4nY, \tilde{Q}\xi = -4n\xi, \tag{2.19}$$

$$\tilde{S}(\phi Y,\phi Z)=S(Y,Z)+(2-6n)g(Y,Z)+2(2n-2)\eta(Y)\eta(Z), \tag{2.20}$$

$$\tilde{r}=r-12n^2+2n, \tag{2.21}$$

$$\tilde{\nabla}_X\xi=2(X-\eta(X)\xi=-2\phi^2X, \tag{2.22}$$

$$\eta(\tilde{R}(X,Y)Z)=2[g(X,Z)\eta(Y)-g(Y,Z)\eta(X)], \tag{2.23}$$

$$\tilde{R}(X,Y)Z+\tilde{R}(Y,Z)X+\tilde{R}(Z,X)Y=0. \tag{2.24}$$

3. Main Results

Theorem 3.1. *There is no weakly symmetric nearly Kenmotsu manifold with semi-symmetric metric connection, unless $\alpha+\gamma+\delta$ is everywhere zero.*

Proof. Assume that M^{2n+1} is a weakly symmetric nearly Kenmotsu manifold. By the covariant differentiation of the semi-symmetric tensor $\tilde{S}$ with respect to X we have

$$(\tilde{\nabla}_X\tilde{S})(Z,V)=\tilde{\nabla}_X\tilde{S}(Z,V)-\tilde{S}(\tilde{\nabla}_XZ,V)-\tilde{S}(Z,\tilde{\nabla}_XV), \tag{3.1}$$

so replacing V with ξ in (3.1) and using (2.2) , (2.4) and (2.15), we obtain

$$\begin{aligned}
&(\tilde{\nabla}_X\tilde{S})(Z,\xi)=\tilde{\nabla}_X\tilde{S}(Z,\xi)-\tilde{S}(\tilde{\nabla}_XZ,\xi)-\tilde{S}(Z,\tilde{\nabla}_X\xi)\\
&=\tilde{\nabla}_X(-4n\eta(Z))+4n\eta(\tilde{\nabla}_XZ)+2\tilde{S}(Z,\varphi^2X)\\
&=-4n\tilde{\nabla}_Xg(Z,\xi)+4n\eta(\tilde{\nabla}_XZ)-2\tilde{S}(Z,X)-8n\eta(X)\eta(Z)\\
&=-4ng(\tilde{\nabla}_XZ,\xi)-4ng(Z,\tilde{\nabla}_X\xi)+4n\eta(\tilde{\nabla}_XZ)-2\tilde{S}(Z,X)-8n\eta(X)\eta(Y)\\
&=8ng(Z,\varphi^2X)-2\tilde{S}(Z,X)-8n\eta(X)\eta(Y)\\
&=-8ng(Z,X)+8n\eta(X)\eta(Y)-2\tilde{S}(Z,X)-8n\eta(X)\eta(Z)
\end{aligned}$$

and

$$(\tilde{\nabla}_X\tilde{S})(Z,\xi)=-8ng(Z,X)-2\tilde{S}(Z,X). \tag{3.2}$$

On the order hand replacing V with ξ in (1.2) and by the use of

$$\begin{aligned}
&(\tilde{\nabla}_X\tilde{S})(Z,\xi)=\alpha(X)\tilde{S}(Z,\xi)+\beta(\tilde{R}(X,Z)\xi)+\gamma(Z)\tilde{S}(X,\xi)+\delta(\xi)\tilde{S}(X,Z)+p(\tilde{R}(X,\xi)Z)\\
&=-4n\alpha(X)\eta(Z)+\beta(2[\eta(X)Z-\eta(Z)X]-4n\gamma(Z)\eta(X)+\delta(\xi)\tilde{S}(X,Z)+p(2[g(X,Z)\xi-\eta(Z)X])\\
&=-4n\alpha(X)\eta(Z)+2\eta(X)\beta(Z)-2\eta(Z)\beta(X)-4n\gamma(Z)\eta(X)+\delta(\xi)\tilde{S}(X,Z)+2g(X,Z)p(\xi)-2\eta(Z)p(X).
\end{aligned} \tag{3.3}$$

Hence, comparing the right hand sides of the equations (3.2) and (3.3) we have

$$\begin{aligned}
-8ng(Z,X)-2\tilde{S}(Z,X)=&-4n\alpha(X)\eta(Z)+2\eta(X)\beta(Z)-2\eta(Z)\beta(X)-4n\gamma(Z)\eta(X)+\delta(\xi)\tilde{S}(X,Z)\\
&+2g(X,Z)p(\xi)-2\eta(Z)p(X).
\end{aligned} \tag{3.4}$$

Therefore putting $X=Z=\xi$ in (3.4) and using (2.15) and (2.1), we get

$$-8n+8n=-4n\alpha(\xi)-4n\gamma(\xi)-4n\delta(\xi), \tag{3.5}$$

$$0=\alpha(\xi)+\gamma(\xi)+\delta(\xi), \tag{3.6}$$

holds on M^{2n+1}. Now we will show that $\alpha+\gamma+\delta=0$ hols for all vektor fields on M^{2n+1}. In (1.2) taking $Z=\xi$ similar to the previous calculations it follows that

$$(\tilde{\nabla}_X\tilde{S})(\xi,V)=\alpha(X)\tilde{S}(\xi,V)+\beta(\tilde{R}(X,\xi)V)+\gamma(\xi)\tilde{S}(X,V)+\delta(V)\tilde{S}(X,\xi)+P(\tilde{R}(X,V)\xi),$$

$$\begin{aligned}
-8ng(V,X)-2n\tilde{S}(V,X)=&-4n\alpha(X)\eta(V)+\beta[2g(X,V)\xi-\eta(V)X]\\
&+\gamma(\xi)\tilde{S}(X,V)-4n\delta8V)\eta(X)+p(2[\eta(X)V-\eta(V)X]),
\end{aligned}$$

$$\begin{aligned}
-8ng(V,X)-2\tilde{S}(V,X)=&-4n\alpha(X)\eta(V)+2g(X,V)\beta(\xi)-2\eta(V)\beta(X)+\gamma(\xi)\tilde{S}(X,V)\\
&-4n\delta(V)\eta(X)+2\eta(X)p(V)-2\eta(V)p(X).
\end{aligned} \tag{3.7}$$

Putting $V=\xi$ in (3.7) by virtue of (2.1) and (2.15), we get

$$-8ng(\xi,X)-2\tilde{S}(\xi,X)=-4n\alpha(X)\eta(\xi)+2g(X,\xi)\beta(\xi)-2\eta(\xi)\beta(X)+\gamma(\xi)\tilde{S}(X,\xi)-4n\delta(\xi)\eta(X)+2\eta(X)p(\xi)-2\eta(\xi)p(X),$$

$$0=-4n\alpha(X)+2\eta(X)\beta(\xi)-2\beta(X)-4n\eta(X)\gamma(\xi)-4n\delta(\xi)\eta(X)+2\eta(X)p(\xi)-2p(X). \tag{3.8}$$

Now taking $X=\xi$ in (3.7), we have

$$-8ng(V,\xi)-2\tilde{S}(V,\xi)=-4n\alpha(\xi)\eta(V)+2g(\xi,V)\beta(\xi)-2\eta(V)\beta(\xi)+\gamma(\xi)\tilde{S}(\xi,V)-4n\delta(V)\eta(\xi)+2\eta(\xi)p(V)-2\eta(V)p(\xi),$$

$$0=-4n\alpha(\xi)\eta(V)-4n\gamma(\xi)\eta(V)-4n\delta(V)+2p(V)-2\eta(V)p(\xi). \tag{3.9}$$

Replacing V with X in (3.9) and summing with (3.8), in view of (3.5), we find

$$0=-4n\alpha(\xi)\eta(X)-4n\eta(X)\gamma(\xi)-4n\delta(X)+2p(X)-2\eta(X)p(\xi)-4n\alpha(X)$$
$$+2\eta(X)\beta(\xi)-2\beta(X)-4n\eta(X)\gamma(\xi)-4n\delta(\xi)\eta(X)+2\eta(X)p(\xi)-2p(X),$$

$$0=-4n\alpha(X)+2\eta(X)\beta(\xi)-2\beta(X)-8n\eta(X)\gamma(\xi)-4n\eta(X)\alpha(\xi)-4n\delta(\xi)\eta(X)-4n\delta(X). \tag{3.10}$$

Now putting $X=\xi$ in (3.4), we have

$$-8ng(Z,\xi)-2\tilde{S}(Z,\xi)=-4n\alpha(\xi)\eta(Z)+2\eta(\xi)\beta(Z)-2\eta(Z)\beta(\xi)-4n\gamma(Z)\eta(\xi)+\delta(\xi)\tilde{S}(\xi,Z)+2g(\xi,Z)p(\xi)-2\eta(Z)p(\xi),$$

$$0=-4n\eta(Z)\alpha(\xi)+2\beta(Z)-2\eta(Z)\beta(\xi)-4n\gamma(Z)-4n\eta(Z)\delta(\xi)+2\eta(Z)p(\xi)-2\eta(Z)p(\xi).$$

$$0=-4n\eta(Z)\alpha(\xi)+2\beta(Z)-2\eta(Z)\beta(\xi)-4n\gamma(Z)-4n\eta(Z)\delta(\xi) \tag{3.11}$$

Replacing Z with X in (3.11) and taking the summation with (3.10), we have

$$0=-4n\eta(X)\alpha(\xi)+2\beta(X)-2\eta(X)\beta(\xi)-4n\gamma(X)-4n\eta(X)\delta(\xi)-4n\alpha(X)$$
$$+2\eta(X)\beta(\xi)-2\beta(X)-8n\eta(X)\gamma(\xi)-4n\eta(X)\alpha(\xi)-4n\eta(X)\delta(\xi)-4n\delta(X),$$

$$0=-8n\eta(X)\alpha(\xi)-8n\eta(X)\gamma(\xi)-8n\eta(X)\delta(\xi)-4n\alpha(X)-4n\gamma(X)-4n\delta(X),$$
$$0=-8n\eta(X)[\alpha(\xi)+\gamma(\xi)+\delta(\xi)]-4n[\alpha(X)+\gamma(X)+\delta(X)].$$

So in view of (3.5), we obtain $\alpha(X)+\gamma(X)+\delta(X)$ for all X on M^{2n+1}. This completes the proof of the theorem. □

Theorem 3.2. *There is no weakly symmetric nearly Kenmotsu manifold with semi-symmetric metric connection, unless $\rho+\mu+\upsilon$ is everywhere zero.*

Proof. Suppose that M^{2n+1} is a weakly symmetric nearly kenmotsu manifold with semi-symmetric metric connection. Replacing Z with ξ in (1.2) and using (2.15) we have

$$(\tilde{\nabla}_X\tilde{S})(Y,\xi)=\rho(X)\tilde{S}(Y,\xi)+\mu(Y)\tilde{S}(X,\xi)+\upsilon(\xi)\tilde{S}(X,Y),$$

$$-8ng(Y,X)-2\tilde{S}(Y,X)=-4n\eta(Y)\rho(X)-4n\eta(X)\mu(Y)+\upsilon(\xi)\tilde{S}(X,Y). \tag{3.12}$$

So in view of (3.12) and (3.2) we obtain

$$-8ng(Y,X)-2\tilde{S}(Y,X)=-4n\eta(Y)\rho(X)-4n\eta(X)\mu(Y)+\upsilon(\xi)\tilde{S}(X,Y). \tag{3.13}$$

Taking $X=Y=\xi$ in (3.13) and by the use of (2.15), (2.1) and (2.2) we get

$$-8ng(\xi,\xi)-2\tilde{S}(\xi,\xi)=-4n\eta(\xi)\rho(\xi)-4n\eta(\xi)\mu(\xi)+\upsilon(\xi)\tilde{S}(\xi,\xi),$$
$$-8n+8n=-4n\rho(\xi)-4n\mu(\xi)-4n\upsilon(\xi),$$
$$0=-4n[\rho(\xi)+\mu(\xi)+\upsilon(\xi)],$$

which gives (since $2n+1$)

$$\rho(\xi)+\mu(\xi)+\upsilon(\xi)=0. \tag{3.14}$$

Now putting $X=\xi$ in (3.13) we have

$$-8ng(Y,\xi)-2\tilde{S}(Y,\xi)=-4n\eta(Y)\rho(\xi)-4n\eta(\xi)\mu(Y)+\upsilon(\xi)\tilde{S}(\xi,Y),$$
$$-8n\eta(Y)+8n\eta(Y)=-4n\eta(Y)\rho(\xi)-4n\mu(Y)+4n\eta(Y)\upsilon(\xi),$$
$$0=-4n\eta(Y)[\rho(\xi)+\upsilon(\xi)]-4n\mu(Y),$$

so by virtue of (3.14) this yields

$$-4n\eta(Y)[-\mu(\xi)]-4n\mu(Y)=0,$$

$$4n[\mu(\xi)\eta(Y)]-4n\mu(Y)=0,$$

which gives us (since $2n+1$)

$$\mu(Y)=\mu(\xi)\eta(Y). \tag{3.15}$$

Similary taking $Y=\xi$ in (3.13) we also have

$$-8ng(\xi,X)-2\tilde{S}(\xi,X)=-4n\eta(\xi)\rho(X)-4n\eta(X)\mu(\xi)+\upsilon(\xi)\tilde{S}(X,\xi),$$

$$-8n\eta(X)-8n\eta(X)=-4n\rho(X)-4n\eta(X)\mu(\xi)-4n\eta(X)\upsilon(\xi),$$

$$0=-4n[\rho(X)+\eta(X)\mu(\xi)+\eta(X)\upsilon(\xi)],$$

$$0=\rho(X)+\eta(X)[\mu(\xi)+\upsilon(\xi)],$$

hence applying (3.14) into the last equation, we find

$$\rho(X)=\rho(\xi)\eta(X). \tag{3.16}$$

Since $(\tilde{\nabla}_X\tilde{S})(\xi,X)=0$,then from (1.2) we obtain $X=Y=\xi$ and $Z=X$

$$(\tilde{\nabla}_X\tilde{S})(\xi,X)=\rho(\xi)\tilde{S}(\xi,X)+\mu(Y)\tilde{S}(\xi,X)+\upsilon(X)\tilde{S}(\xi,\xi),$$

$$0=-4n\eta(X)\rho(\xi)-4n\eta(X)\mu(\xi)-4n\upsilon(X),$$

$$0=\eta(X)\rho(\xi)+\eta(Y)\mu(\xi)+\upsilon(X),$$

$$0=\eta(X)[\rho(\xi)+\mu(\xi)]+\upsilon(X).$$

So by making use of (3.14) the last equation reduces to

$$\upsilon(X)=\upsilon(\xi)\eta(X). \tag{3.17}$$

Therefore changing Y with X in (3.15) and by the summation of the equations (3.15), (3.16) and (3.17), we obtain

$$\rho(X)+\mu(X)+\upsilon(X)=\eta(X)[\rho(\xi)+\mu(\xi)+\upsilon(\xi)]$$

and so in view of (3.14) it follows that

$$\rho(X)+\mu(X)+\upsilon(X)=0$$

for all X, which implies $\rho+\mu+\upsilon=0$ on M^{2n+1}. Our theorem is thus proved. □

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