DEFORMED INFINITE SERIES METRIC IN CARTAN SPACES

Brijesh Kumar Tripathi and V. K. Chaubey

Communicated by Simon Donaldson

MSC 2010 Classifications: Primary 53C60; Secondary 53B40.

Keywords and phrases: Finsler space, Cartan Space, \((\alpha,\beta)\)-metrics, Riemannian metric, One form metric, Infinite series metric.

Abstract Igarashi introduce the concept of \((\alpha,\beta)\)-metric in Cartan space \(\ell^n\) analogously to one in Finsler space and obtained the basic important geometric properties and also investigate the special class of the space with \((\alpha,\beta)\)-metric in \(\ell^n\) in terms of \('invariants'\). In the present paper, we determine the \('invariants'\) in two different cases of deformed infinite series metric, which characterize the special classes of Cartan spaces \(\ell^n\). Further, we investigate some classes of deformed infinite series spaces and obtain deformed infinite series class which will provide the example of Cartan spaces.

1 Introduction

In 2004, Lee and Park [8] introduced the concept of \(r^{th}\) series \((\alpha,\beta)\)-metric where \(r\) varies from \(0, 1, 2, ..., \infty\) and gave an interesting example of special \((\alpha,\beta)\)-metric for the different values of \(r\) such as one-form metric, Randers metric, combination of Kropina and Randers metric, infinite series metric etc.

In 2001, Sorin Sabau and H. Shimada [17] investigated some classes of \((\alpha,\beta)\)-metric spaces and obtained Randers class, Kropina class and Matsumoto class. These classes provided a concrete examples of Finsler spaces with \((\alpha,\beta)\)-metrics.

In 1994, Igarashi [5, 6] introduce the concept of \((\alpha,\beta)\)-metric in Cartan space \(\ell^n\) analogously to one in Finsler space and obtained the basic important geometric properties and also investigate the special class of the space with \((\alpha,\beta)\)-metric in \(\ell^n\) in terms of \('invariants'\). The classes which he obtained includes the spaces corresponding to Randers and Kropina space. Further, he characterizes these spacial classes by means of \('invariants'\) in case of Finsler theory.

In the present paper, we determine the \('invariants'\) in two different cases of deformed infinite series metric, wherein first metric is defined as the product of infinite series and Riemannian metric. Whereas, the other one is the product of infinite series and one-form metric. Further, we characterize the special classes of Cartan spaces \(\ell^n\) in case of these two metrics and also investigate the relation under which "invariants" are characterized as the special classes of \(\ell^n\). As a special case, we investigate some classes of deformed infinite series spaces and obtained deformed infinite series class which will provide the example of Cartan spaces.

2 Preliminaries

E. Cartan [3] introduced the concept of a Cartan Space, where the measure of its hypersurface element \((x, y)\) is given a priori by homogeneous function \(F(x, y)\) of degree one in \(y, \text{i.e., the "area" of a domain on hypersurface } S_{n-1} : x^i = x^i(v^1, v^2, v^3, ..., v^n), \quad i = 1, 2, 3, ..., n \text{ is given by} \)

\[
S = \int \cdots \int F(x, y)dv^1dv^2dv^3.....dv^{n-1} \quad (2.1)
\]
where \( y = (y_i) \) is the determinant of \((n - 1, n - 1)\) minor matrix omitting \(i^{th}\) row of \((n, n - 1)\) matrix \(\frac{\partial g}{\partial v^i}\), \(\alpha = 1, 2, 3,..., n - 1\). The fundamental tensor given by

\[
g^{ij} = G^{- \frac{1}{2}}, \quad G = det\|G^{ij}\|, \quad G^{ij} = \frac{\partial g^2(\frac{1}{2} F^2)}{\partial y_i \partial y_j}, \quad (y_i) \neq 0. \tag{2.2}
\]

As the special case for the fundamental tensor \(a_{ij}\) of Riemannian space, given as the \((n - 1)\) dimensional area of a domain on hypersurface such that

\[
S = \int \cdots \int \sqrt{det[a_{ij}(x)]} \, dv^1 dv^2 dv^3 \ldots \ldots dv^{n-1}
\]

Therefore, it clear that Riemannian space is a special case of Cartan space. On the other hand, Cartan space is considered as the dual notion of Finsler Space. Earlier, L. Berwald [1] has studied the relation between both spaces. Thereafter, H. Rund [15] and F.Brickel [2] carry forwarded the same study. R. Miron [13, 14] established new Carton geometry which shows totally different feature in the form of particularization the Hamilton space which defined as:

**Definition 2.1.** A Cartan space is a Hamilton space \( \mathcal{H}^n = \{M, H(x, y)\} \) in which the fundamental function \( H(x, y) \) is positively 2-homogeneous in \( y_i \) on \( T^* M \). We denote it by \( \ell^n \).

The fundamental tensor field of \( \ell^n \) and its reciprocal \( g_{ij}(x, y) \) is given by

\[
g^{ij}(x, y) = \frac{1}{2} \partial^i \partial^j H, \tag{2.3}
\]

\[
g_{ij}(x, y)g^{jk}(x, y) = \delta^k_i \tag{2.4}
\]

The homogeneity of \( H(x, y) \) is expressed by

\[
y_j \partial_j H = 2H, \text{ which also implies } H = g^{ij}y_i y_j \tag{2.5}
\]

where \( g^{ij}(x, y) \) and its reciprocal \( g_{ij}(x, y) \) are both symmetric and homogeneous of degree 0 in \( y_i \).

In 1996, D. Hrimiuc and H. Shimada [4] expressed the definitions of Lagrange, Hamilton and Cartan Spacces with examples:

**Definition 2.2.** A regular Lagrangian (Hamiltonian) on a domain \( D \subset TM \ (D^* \subset T^* M) \) is a real smooth function \( L : D \rightarrow R(H : D^* \rightarrow R) \) such that the matrix with entries

\[
g_{ij}(x, y) = \partial_i \partial_j L(x, y) \quad (g^{*ij}(x, y) = \partial^i \partial^j H(x, y)) \tag{2.6}
\]

is everywhere nondegenerate on \( D(D^*) \).

A Lagrange (Hamilton) manifold is a pair \((M, L) ((M, H))\) where \( M \) is smooth manifold and \( L(H) \) is a regular Lagrangian (Hamiltonian) on \( D(D^*) \).

**Examples:**

1: Every Finsler Space \( F^n = (M, F(x, y)) \) is Lagrange Manifold with \( L = \frac{F^2}{2} \).

2: Every Cartan Space \( \ell^n = (M, F(x, p)) \) is a Hamilton Manifold with \( H = \frac{1}{2} F^2 \). (Here \( F \) is positively 1-homogeneous in \( p_i \) and the tensor \( \tilde{g}^{ij} = \frac{1}{2} \partial^i \partial_j F^2 \) is nondegenerate.)

3: \((M, L) \) and \((M, H)\) with

\[
L(x, y) = a_{ij}(x)y^i y^j + b_i(x)y^i + c(x) \\
H(x, p) = \tilde{g}^{ij}(x)p_ip_j + \tilde{F}(x)p_i + \tilde{c}(x)
\]

are Lagrange and Hamilton Manifold respectively.

On the other hand, the Finsler spaces with \((\alpha, \beta)\)-metric were considered by G. Randers [15], V. K. Kropina [7] and M. Matsumoto [10, 11, 12], especially the last paper shows the great success for investigation of these spaces.
In [13], R. Miron expected the existence of Randers type metric:

\[ H(x, y) = \{\alpha(x, y) + \beta(x, y)\}^2 \] (2.7)

and of Kropina’s one:

\[ H(x, y) = \left(\frac{\alpha(x, y)}{\beta(x, y)}\right)^2, \quad \beta(x, y) \neq 0. \] (2.8)

in Cartan spaces. Here we have put as

\[ \alpha^2(x, y) = a_{ij}(x) y_i y_j, \quad \beta(x, y) = b^i(x) y_i, \] (2.9)

\( a_{ij}(x) \) being a Riemannian metric on the base manifold \( M \) and \( b^i(x) \) a vector field on \( M \) such that \( \beta > 0 \) on a region of \( T^*M \).

### 3 Cartan spaces with \((\alpha, \beta)\)-metric.

Cartan spaces with \((\alpha, \beta)\)-metric [5, 6, 13] can be defined:

**Definition 3.1.** A Cartan space \( \ell^n = \{M, H(x, y)\} \) is known as Cartan space with \((\alpha, \beta)\)-metric if its fundamental metric \( H(x, y) \) is a function of \( \alpha(x, y) \) and \( \beta(x, y) \) only i.e.

\[ H(x, y) = \tilde{H}\{\alpha(x, y), \beta(x, y)\} \] (3.1)

It is clear that \( \tilde{H} \) satisfy the conditions imposed to the function \( H(x, y) \) as a fundamental function for \( \ell^n \). Then

\[ t\alpha(x, y) = \alpha(x, ty), \quad t\beta(x, y) = \beta(x, ty), \quad H(x, ty) = t^2 H(x, y) \quad t > 0. \] (3.2)

It follows:

**Proposition 3.2.** The function \( \tilde{H}\{\alpha(x, y), \beta(x, y)\} \) is positively homogeneous of degree 2 in both \( \alpha \) and \( \beta \).

By this reason, there maybe no confusion if we adopt the notation \( H(\alpha, \beta) \) itself instead of \( \tilde{H}(\alpha, \beta) \). It can also be written;

\[ H_\alpha = \frac{\partial H}{\partial \alpha}, \quad H_\beta = \frac{\partial H}{\partial \beta}, \quad H_{\alpha\beta} = \frac{\partial^2 H}{\partial \alpha \partial \beta}, \quad \text{etc} \] (3.3)

**Proposition 3.3.** The following identities hold:

\[ \alpha H_{\alpha\alpha} + \beta H_{\beta\beta} = H, \quad \alpha H_{\alpha\beta} + \beta H_{\beta\beta} = H_\beta, \] (3.4)

\[ \alpha^2 H_{\alpha\alpha} + 2\alpha\beta H_{\alpha\beta} + \beta^2 H_{\beta\beta} = \alpha H_\alpha + \beta H_\beta = 2H. \]

Differentiating \( \alpha \) and \( \beta \) with respect to \( y_i \) we have

\[ \dot{\alpha}^i = \alpha^{-1} a^{ij} y_j = \alpha^{-1} Y^i, \quad \dot{\beta}^i = b^i(x), \] (3.5)

where

\[ Y^i(x, y) = a^{ij}(x) y_j, \quad \{Y = (Y^i)\} \neq 0 \] (3.6)

and the vector field \( Y^i \) satisfies the relation

\[ Y^i y_i = \alpha^2, \] (3.7)

Further let

\[ B_i(x) = a_{ij}(x) b^j(x), \quad B^2(x) = a^{ij} B_i B_j = a_{ij} b^i b^j, \] (3.8)
\[ g^i(x, y) = g^{ij}(x, y)y_j = \frac{1}{2} \frac{\partial H}{\partial y_i} \]  
(3.9)

Also, we have the relation similar to (3.7):

\[ y^i y_i = H(x, y). \]  
(3.10)

Differentiating (3.6) and (3.9) by \( y_i \), successively, we have

\[ \partial_i Y^i = a^{ij}(x), \quad \partial_i \partial_j Y^i = 0, \]  
(3.11)

\[ \partial_i y^i = g^{ij}, \quad \partial_i \partial_j y^i = \partial_i g^{ij} = -2C^{ijk}, \]  
(3.12)

And using the same manner for (3.5), we get

\[ \partial^i \partial^j \alpha = \alpha^{-1} a^{ij}(x) - \alpha^{-3} Y^i Y^j, \quad \partial^i \partial^j \beta = 0, \quad \partial^i \partial^j \left( \frac{1}{2} \alpha^2 \right) = a^{ij}. \]  
(3.13)

On account of (3.5) and \( y^i = \frac{1}{2}(H_{\alpha\beta} \partial^\alpha \alpha + H_{\beta\beta} \partial^\beta \beta) \), we have

**Lemma 3.4.** The Liouville vector field \( y^i \) is expressed in the form

\[ y^i = \rho_1 b^i + \rho Y^i, \]  
(3.14)

where

\[ \rho_1 = \frac{1}{2} H_{\alpha\beta}, \quad \rho = \frac{1}{2\alpha} H_{\alpha}. \]  
(3.15)

Taking into account that the relation \( \partial^i \rho = \frac{\partial \alpha}{\partial_{\alpha}} \partial^i \alpha + \frac{\partial \beta}{\partial_{\beta}} \partial^i \beta \) holds, we have

**Lemma 3.5.** The quantities \( \rho_1 \) and \( \rho \) satisfy the relations

\[ \partial^i \rho_1 = \rho_0 b^i + \rho_{-1} Y^i, \quad \partial^i \rho = \rho_{-1} b^i + \rho_{-2} Y^i \]  
(3.16)

respectively, where

\[ \rho_0 = \frac{1}{2} H_{\beta\beta}, \quad \rho_{-1} = \frac{1}{2\alpha} H_{\alpha\beta}, \quad \rho_{-2} = \frac{1}{2\alpha^2} (H_{\alpha\alpha} - \alpha^{-1} H_{\alpha}). \]  
(3.17)

Contracting \( \partial^i \rho_1, \partial^i \rho \) in (3.16) by \( y_i \), we have

\[ y_i \partial^i \rho_1 = \alpha^2 \rho_{-1} + \beta \rho_0 = \rho_1, \quad y_i \partial^i \rho = \alpha^2 \rho_{-2} + \beta \rho_{-1} = 0. \]  
(3.18)

Analogously to deduction of Lemma (3.2), we have also

**Lemma 3.6.** The quantities \( \rho_0 \) and \( \rho_{-1} \) satisfy the relations

\[ \partial^i \rho_0 = r_{-1} b^i + r_{-2} Y^i, \quad \partial^i \rho_{-1} = r_{-2} b^i + r_{-3} Y^i, \]  
(3.19)

respectively, where

\[ r_{-1} = \frac{1}{2} H_{\beta\beta}, \quad r_{-2} = \frac{1}{2\alpha} H_{\alpha\beta}, \quad r_{-3} = \frac{1}{2\alpha^2} (H_{\alpha\alpha} - \alpha^{-1} H_{\alpha\beta}). \]  
(3.20)

Corresponding to (3.18), it follows

\[ y_i \partial^i \rho_0 = \alpha^2 r_{-2} + \beta r_{-1} = 0, \quad y_i \partial^i \rho_{-1} = \alpha^2 r_{-3} + \beta r_{-2} = -\rho_{-1}. \]  
(3.21)

Furthermore for \( \rho_{-2} \), we have

**Lemma 3.7.** The quantities \( \rho_{-2} \) satisfies the relations

\[ \partial^i \rho_{-2} = r_{-3} b^i + r_{-4} Y^i \]  
(3.22)

\[ r_{-4} = \frac{1}{2\alpha^3} (H_{\alpha\alpha \alpha} - 3\alpha^{-1} H_{\alpha\alpha} + 3\alpha^{-2} H_{\alpha}). \]  
(3.23)
Also following homogeneity holds good:

\[ y_i \partial^i \rho_{-2} = \alpha^2 r_{-4} + \beta r_{-3} = -2 \rho_{-2}. \]  
\[ (3.24) \]

It is easy to conclude for the scalars (or invariants) \( \rho_1, \rho, \rho_0, \rho_{-1}, \ldots, r_{-1}, r_{-2}, \ldots \) in the above lemmas that subscript of \( \rho, s \) and \( r, s \) represent degree of their own homogeneity in \( (\alpha, \beta) \) or \( y_i \), where the \( \rho \) without subscript means of degree 0.

We have these properties from expressions in (3.18),(3.19) and (3.21) and the following relations

\[ y_i \partial^i r_{-1} = -r_{-1}, \quad y_i \partial^i r_{-2} = -2r_{-2}, \]
\[ (3.25) \]

\[ y_i \partial^i r_{-3} = -3r_{-3}, \quad y_i \partial^i r_{-4} = -4r_{-4}, \]

because of the homogeneity of

\[ \alpha H_{\alpha \alpha \alpha} + \beta \alpha \alpha \beta = -H_{\alpha \alpha \alpha}, \quad \alpha H_{\alpha \alpha \beta} + \beta \alpha \beta \beta = -H_{\alpha \alpha \beta}, \]
\[ (3.26) \]

\[ \alpha H_{\alpha \beta \beta} + \beta \alpha \beta \beta = -H_{\alpha \beta \beta}, \quad \alpha H_{\beta \alpha \beta} + \beta H_{\beta \beta \beta} = -H_{\beta \beta \beta}. \]

We shall use the previous results to study the fundamental geometric objects of the space \( \ell^n \) with \( (\alpha, \beta) \)-metric. All these scalar functions \( \rho_1, \rho, \rho_0, \rho_{-1}, \ldots \) as well as \( r_{-1}, r_{-2}, \ldots \) will be called the invariants of the Cartan space \( \ell^n \) with the fundamental function \( H(\alpha, \beta) \).

### 4 The fundamental tensor of the space \( \ell^n \) with \( (\alpha, \beta) \)-metric.

We need to derive the fundamental tensor from the fundamental function \( H(x, y) \) of the Cartan space \( \ell^n \).

**Theorem 4.1.** The fundamental tensor \( g^{ij} \) of Cartan space \( \ell^n \) with \( (\alpha, \beta) \)-metric is given by

\[ g^{ij} = \rho a^{ij} + \rho b^i b^j + \rho_{-1}(b^i Y^j + b^j Y^i) + \rho_{-2} Y^i Y^j, \]
\[ (4.1) \]

where \( \rho, \rho_0, \rho_{-1}, \rho_{-2} \) are the invariants given by (3.15) and (3.17).

**Proof.** Making use of (3.12) and (3.14), we have

\[ g^{ij} = \partial^i y^j = \partial^i (\rho_1 b^i + \rho Y^i) = (\partial^i \rho_1) b^i + (\partial^i \rho) Y^i + \rho a^{ij}. \]

Taking into account Lemma (3.2), we have (3.1). Q.E.D.

In order to check the fitness of this tensor \( g^{ij} \) for the fundamental tensor of \( (\alpha, \beta) \)-metric, we verify the homogeneity of \( g^{ij} \). Contracting \( g^{ij} \) by \( y_i \) and \( y_j \), we have

\[
g^{ij} y_i y_j = \frac{1}{2} \left\{ \alpha^{-1} H_{\alpha \alpha} a^{ij} y_i y_j + (\alpha^{-2} H_{\alpha \alpha} - \alpha^{-3} H_{\alpha}) Y^i Y^j y_i y_j \right. \\
+ \alpha^{-1} H_{\alpha \beta} (Y^i y_i b^j y_j + b^i y_i Y^j y_j) + \beta \alpha \alpha \beta \alpha \beta \right. \\
= \frac{1}{2} \left\{ \alpha H_{\alpha} + (\alpha^{-2} H_{\alpha \alpha} - \alpha^{-3} H_{\alpha}) \alpha \beta \beta \alpha \beta \right. \\
+ \alpha^{-1} H_{\beta \alpha \beta} \right. \\
= \frac{1}{2} \cdot 2 H = H.
\]

which shows that our conclusion is right.

Let us rewrite this expression in the form

\[ g^{ij} = A^{ij} + C^i C^j, \]
\[ (4.2) \]

where

\[ A^{ij} = \rho a^{ij}, \quad C^i = q_0 b^i + q^{-1} Y^i, \]
\[ (4.3) \]

\[ \rho_0 = q_0^2, \quad \rho_{-1} = q_0 q_{-1}, \quad \rho_{-2} = q_{-1}^2 \]
\[ (4.4) \]

and

\[ \rho_0 \rho_{-2} = \rho_{-1}^2 \]
\[ (4.5) \]
The reciprocal tensor $g_{ij}$ of $g^{ij}$ are given by

$$g_{ij} = A_{ij} - \frac{1}{1 + C^2} C_i C_j,$$  \hspace{1cm} (4.6)

where

$$\det \| A_{ij} \| = (1 + C^2) \det \| A^{ij} \| \quad (i f 1 + C^2 \neq 0),$$  \hspace{1cm} (4.7)

and $A_{ij}, C_i$ are given by

$$A_{ij} A^{jk} = \delta^i_j, \quad C^i = A^{ij} C_j, \quad C_i = A_{ij} C^j.$$  \hspace{1cm} (4.8)

Consequently, we have $g_{ij}(x,y)g_{jk}(x,y) = \delta^i_k$, and

$$\text{rank} \| g_{ij}(x,y) \| = n \quad \text{because of}$$

where we use the notations

$$B^2 = a^{ij} b_i b_j, \quad \tau = \rho + \rho_0 B^2 + \rho_{-1} \beta.$$  \hspace{1cm} (4.11)

Therefore we can prove without difficulty:

**Proposition 4.2.** The covariant form of the fundamental tensor is given by

$$g_{ij} = \sigma a_{ij} - \sigma_0 B_i B_j + \sigma_{-1} (B_i y_j + B_j y_i) + \sigma_{-2} y_i y_j,$$  \hspace{1cm} (4.12)

where we use the notations

$$\sigma = \frac{1}{\rho}, \quad \sigma_0 = \frac{\rho_0}{\rho \tau}, \quad \sigma_{-2} = \frac{\rho_{-2}}{\rho \tau}.$$  \hspace{1cm} (4.13)

We can get another result from the Lemma (3.4) such that

**Theorem 4.3.** The Cartan tensor $C^{ijk}$ of a Cartan space $\ell^n$ with $(\alpha, \beta)$-metric is given by

$$C^{ijk} = \frac{-1}{2} [r_{-1} b^i b^j b^k + \Pi_{ijk} (r_{-1} a^{ij} b^k + r_{-2} a^{ij} Y^k + r_{-3} b^i Y^j Y^k + r_{-4} Y^i Y^j Y^k)]$$  \hspace{1cm} (4.14)

where the notation $\Pi_{ijk}$ means the cyclic symmetrization of the quantity in the brackets with respect to indices i, j, k.

We can deduce the other important geometric object fields for $\ell^n$ with $(\alpha, \beta)$-metric. For instance, $N_{ij}, H_{ijk}, C^{ijk}$ etc. without difficulty.

5 Cartan spaces with infinite series of $(\alpha, \beta)$-metric

In 2004, Lee and Park [8] introduced a $r$-th series $(\alpha, \beta)$-metric

$$L(\alpha, \beta) = \beta \sum_{k=0}^{r} \left( \frac{\alpha}{\beta} \right)^k,$$  \hspace{1cm} (5.1)
where they assume $\alpha < \beta$. If $r = 1$ then $L = \alpha + \beta$ is a Randers metric. If $r = 2$ then $L = \alpha + \beta + \frac{\alpha^2}{\beta - \alpha}$ is a combination of Randers metric and Kropina metric. If $r = \infty$ then above metric is expressed as

$$L(\alpha, \beta) = \frac{\beta^2}{\beta - \alpha} \tag{5.2}$$

and the metric (5.2) named as infinite series $(\alpha, \beta)$-metric. This metric is very remarkable because it is the difference of Randers and Matsumoto metric.

In this section, we consider two cases of Cartan Finsler spaces with special $(\alpha, \beta)$-metrics of deformed infinite series metric which are defined as

I. $H(\alpha, \beta) = \alpha^3 \frac{\beta}{\beta - \alpha}$ i.e. the product of infinite series and Riemannian metric.

II. $H(\alpha, \beta) = \beta^3 \frac{\alpha}{\beta - \alpha}$ i.e. the product of infinite series and one-form metric.

5.1 Cartan space $\ell^n$ for $H(\alpha, \beta) = \alpha^3 \beta \frac{\alpha}{\beta - \alpha}$

In the first case, partial derivatives of the fundamental function $H(\alpha, \beta)$ lead us the followings:

$$H_\alpha = \frac{\beta^3}{(\beta - \alpha)^3}, \quad H_\beta = \frac{\alpha^3 - 2\alpha^2 \beta}{(\beta - \alpha)^2}, \quad H_{\alpha \alpha} = \frac{6\alpha^3}{(\beta - \alpha)^4}, \quad H_{\alpha \beta} = -\frac{6\alpha^2 \beta^2}{(\beta - \alpha)^3}, \quad H_{\beta \beta} = \frac{6\alpha^2 \beta}{(\beta - \alpha)^4}$$

Using equation (3.15) and (3.17) we have following invariants

$$\rho_1 = \frac{\alpha^2}{2(\beta - \alpha)^2}, \quad \rho = \frac{\beta^3}{2(\beta - \alpha)^2}, \quad \rho_0 = \frac{\alpha^3}{(\beta - \alpha)^3}, \quad \rho_{-1} = \frac{\beta^3 - 3\alpha^2 \beta}{2\alpha(\beta - \alpha)^3}, \quad \rho_{-2} = \frac{\beta^3(3\alpha - \beta)}{2\alpha^3(\beta - \alpha)^4} \tag{5.3}$$

**Proposition 5.1.** The invariants $\rho$ never vanishes in a Cartan space $\ell^n$ equipped with deformed infinite series metric function $H(\alpha, \beta) = \alpha^3 \beta \frac{\alpha}{\beta - \alpha}$ metric on $\tilde{T}^n M$. Conversely, we have $H_\alpha \neq 0$ on $\tilde{T}^n M$.

Again using equation (3.20) and (3.23) we have following invariants

$$r_{-1} = \frac{-3\alpha^3}{(\beta - \alpha)^4}, \quad r_{-2} = \frac{3\alpha \beta}{(\beta - \alpha)^4}, \quad r_{-3} = \frac{4\alpha^3 \beta^3 - \beta^4 - 9\alpha^2 \beta^2}{2\alpha^3(\beta - \alpha)^4}, \quad r_{-4} = \frac{15\alpha^2 \beta^3 + 3\beta^5 - 12\alpha \beta^4}{2\alpha^3(\beta - \alpha)^4} \tag{5.4}$$

**Proposition 5.2.** The invariants of Cartan tensor $C^{ijk}$ in Cartan space $\ell^n$ which equipped with deformed infinite series metric function $H(\alpha, \beta) = \alpha^3 \beta \frac{\alpha}{\beta - \alpha}$ is given by (5.3) and (5.4).

The invariants of equations (5.3) and (5.4) satisfies the following relations

$$\alpha^2 \rho_{-1} + \beta \rho_0 = \rho_1, \quad \alpha^2 \rho_{-2} + \beta \rho_{-1} = 0 \tag{5.5}$$

$$\alpha^2 r_{-2} + \beta r_{-1} = 0, \quad \alpha^2 r_{-3} + \beta r_{-2} = -\rho_{-1}, \quad \alpha^2 r_{-4} + \beta r_{-3} = -2\rho_{-2}$$

**Theorem 5.3.** The Cartan space $\ell^n$ equipped with deformed infinite series metric function $H(\alpha, \beta) = \alpha^3 \beta \frac{\alpha}{\beta - \alpha}$ has the invariants in equations (5.3) and (5.4) are satisfied the relations in (5.5).
Using equation (3.15) and (3.17) we have following invariants:

$$g^{ij}(x, y) = \frac{\beta^3}{2(\beta - \alpha)^2} a^{ij} + \frac{\alpha^3}{(\beta - \alpha)^3} b^i b^j + \frac{\beta^3 - 3\alpha\beta^2}{2(\beta - \alpha)^3}(b^i Y^j + b^j Y^i)$$  \hspace{1cm} (5.6)

Corollary 5.4. The fundamental tensor $g^{ij}(x, y)$ of the space $\ell^n$ endowed with the metric function $H(\alpha, \beta) = \frac{\alpha^3}{\beta - \alpha}$ is given by the equation (5.6).

Conversely, we obtain

Theorem 5.5. The Cartan space with $(\alpha, \beta)$-metric which have the invariants such that (5.3) and (5.4) is the spaces $\ell^n$ with the fundamental function $H(\alpha, \beta) = \frac{\alpha^3}{\beta - \alpha}$, i.e. deformed infinite series metric.

5.2 Cartan space $\ell^n$ for $H(\alpha, \beta) = \frac{\beta^3}{\beta - \alpha}$

In the second case, partial derivatives of the fundamental function $H(\alpha, \beta)$ lead us the followings:

$$H_\alpha = \frac{\beta^3}{(\beta - \alpha)^2}, \quad H_\beta = \frac{2\beta^3 - 3\alpha\beta^2}{(\beta - \alpha)^3},$$

$$H_{\alpha\alpha} = \frac{\beta^3}{(\beta - \alpha)^2}, \quad H_{\alpha\beta} = \frac{6\alpha\beta^2}{(\beta - \alpha)^3}, \quad H_{\beta\beta} = \frac{2\beta^3 - 6\alpha\beta^2 + 3\alpha^2 \beta}{(\beta - \alpha)^3}, \quad H_{\alpha\beta\beta} = \frac{6\alpha^2 \beta}{(\beta - \alpha)^3}.$$  \hspace{1cm} (5.7)

Using equation (3.15) and (3.17) we have following invariants

$$\rho_1 = \frac{2\beta^3 - 3\alpha\beta^2}{2(\beta - \alpha)^2}, \quad \rho = \frac{\beta^3}{2(\beta - \alpha)^2}, \quad \rho_0 = \frac{\beta^3 - 3\alpha\beta^2 + 3\alpha^2 \beta}{(\beta - \alpha)^3}.$$  \hspace{1cm} (5.8)

Proposition 5.6. The invariants $\rho$ never vanishes in a Cartan space $\ell^n$ equipped with deformed infinite series metric function $H(\alpha, \beta) = \frac{\beta^3}{\beta - \alpha}$ metric on $T^*M$. Conversely, we have $H_\alpha \neq 0$ on $\tilde{T}^*\tilde{M}$.

Again using equations (3.20) and (3.23) we have following invariants

$$r_{-1} = -\frac{3\alpha^3}{(\beta - \alpha)^4}, \quad r_{-2} = \frac{3\alpha\beta}{(\beta - \alpha)^4}, \quad r_{-3} = \frac{4\alpha^3 - 8\alpha\beta^2}{2\alpha^3(\beta - \alpha)^4}, \quad r_{-4} = \frac{15\alpha^2 \beta^3 + 3\beta^5 - 12\alpha^2 \beta^4}{2\alpha^5(\beta - \alpha)^4}.$$  \hspace{1cm} (5.9)

Proposition 5.7. The invariants of Cartan tensor $C^{ijk}$ in Cartan space $\ell^n$ which equipped with deformed infinite series metric function $H(\alpha, \beta) = \frac{\beta^3}{\beta - \alpha}$ is given by (5.7) and (5.8).

The invariants of equations (5.7) and (5.8) satisfy the following relations

$$\alpha^2 \rho_{-1} + \beta \rho_0 = \rho_1, \quad \alpha^2 \rho_{-2} + \beta \rho_{-1} = 0,$$

$$\alpha^2 r_{-2} + \beta r_{-1} = 0, \quad \alpha^2 r_{-3} + \beta r_{-2} = -\rho_{-1},$$

$$\alpha^2 r_{-4} + \beta r_{-3} = -2 \rho_{-2}.$$
Theorem 5.8. The Cartan space \( \ell^n \) equipped with deformed infinite series metric function \( H(\alpha, \beta) = \frac{\beta^3}{\beta - \alpha} \) has the invariants in equations (5.7) and (5.8) satisfy the relations in (5.9).

From equation (5.7) and (5.8), the fundamental tensor \( g^{ij}(x, y) \) is of the form

\[
g^{ij}(x, y) = \frac{\beta^3}{2(\beta - \alpha)^2} a^{ij} + \frac{\beta^3 - 3\alpha \beta^2 + 3\alpha^2 \beta}{(\beta - \alpha)^3} b^i b^j + \frac{\beta^3(3\alpha - \beta)}{2\alpha^2(\beta - \alpha)^3} Y^i Y^j \tag{5.10}
\]

Corollary 5.9. The fundamental tensor \( g^{ij}(x, y) \) of the space \( \ell^n \) endowed with the metric function \( H(\alpha, \beta) = \frac{\beta^3}{\beta - \alpha} \) is given by the equation (5.10).

Conversely, we obtain

Theorem 5.10. The Cartan space with \((\alpha, \beta)\)-metric which have the invariants such that (5.7) and (5.8) is the spaces \( \ell^n \) with the fundamental function \( H(\alpha, \beta) = \frac{\beta^3}{\beta - \alpha} \), i.e. deformed infinite series metric.

6 Cartan Classes of Deformed Infinite Series Metric

In 2001 and 2003, S S Vasile and H. Shimada [17, 18] developed the concept of Classes of \((\alpha, \beta)\)-metrics and further they studied classes of Randers, Kropina and Matsumoto metric. In this section, we consider invariants defined in (5.3), (5.4), (5.7) and (5.8) and find the classes of deformed infinite series metric by direct integration.

Since

\[
H_{\beta \beta \beta} = 2r_{-1} = \frac{-6\alpha^3}{(\beta - \alpha)^4}
\]

Integrating equation (6.1) w.r.t. \( \beta \), we have

\[
H_{\beta \beta} = \frac{2\alpha^3}{(\beta - \alpha)^3} + f_1(\alpha)
\]

Again integrating equation (6.2) w.r.t. \( \beta \), we have

\[
H_{\beta} = \frac{-\alpha^3}{(\beta - \alpha)^2} + f_1(\alpha)\beta + f_2(\alpha)
\]

Again integrating equation (6.3) w.r.t. \( \beta \), we have

\[
H = \frac{\alpha^3}{(\beta - \alpha)} + f_1(\alpha)\frac{\beta^2}{2} + f_2(\alpha)\beta + f_3(\alpha)
\]

Thus equation (6.4) written as

\[
H(\alpha, \beta) = \frac{\alpha^3}{(\beta - \alpha)} + C_1 \alpha^2 + 2C_2 \alpha \beta + C_3 \beta^2
\]

Theorem 6.1. A Cartan Space with an \((\alpha, \beta)\)-metric satisfying

\[
r_{-1} = \frac{-3\alpha^4}{(\beta - \alpha)^3}
\]

has the fundamental function of the form (6.5), where \( C_1, C_2 \) and \( C_3 \) are real constants.

Corollary 6.2. If \( C_1 = 1, C_2 = \frac{1}{2} \) and \( C_3 = 0 \), then equation (6.5) gives

\[
H(\alpha, \beta) = \frac{\alpha \beta^2}{(\beta - \alpha)}
\]

i.e. product of Riemannian and infinite series metric.
Corollary 6.3. If \( C_1 = 1, C_2 = \frac{1}{2} \) and \( C_3 = 1 \), then equation (6.5) gives

\[
H(\alpha, \beta) = \frac{\beta^3}{(\beta - \alpha)}
\]

i.e. product of one form and infinite series metric.

Corollary 6.4. If \( C_1 = 0, C_2 = 0 \) and \( C_3 = 0 \), then equation (6.5) gives

\[
H(\alpha, \beta) = \frac{\alpha^3}{(\beta - \alpha)} = -\frac{\alpha^3}{(\alpha - \beta)}
\]

i.e. product of Riemannian and Matsumoto metric with negative sign.

Definition 6.5. Thus, we can call the metric (6.5) as the Cartan deformed infinite series class of \((\alpha, \beta)\) metric.

7 Conclusions

In this work, we consider the infinite series \((\alpha, \beta)\)-metric, Riemannian metric and 1-form metric and we determine relations with the invariants which characterize the special classes in Cartan Finsler frames. Further, we determine Cartan class of \((\alpha, \beta)\)-metric for deformed infinite series metric and discuss some special cases as well. The authors [19] have developed a non-holonomic frames for Finsler space with infinite series of \((\alpha, \beta)\)-metric as an important work for present metric. In future, we can determine L dual relation between Finsler space and Lagrange Space for present metric. Moreover, hypersurfaces of nonholonomic frame for Finsler Space with deformed infinite series metric and some homogeneous frame can also be considered for future work. But, in Finsler geometry, there are many \((\alpha, \beta)\)-metrics, and such frames can be determined in future as well.

References

[1] Berwald, L., Über Finslersche und Cartansche Geometric I,III,IV, Mathematica Cluj, 16, (1940); Compositio Mathematica, 7, (1939), 141-176; Ann. Math., 42, (1941), 84-112; 48, (1947), 755-781.

[2] Brickell, F., A relation between Finsler and Cartan structures, Tensor, N. S., 25, (1972), 360-364.

[3] Cartan, E., Less spaces metriques fondes sur la notion d’aire, Actuarites Sci. Ind., no. 72, Hermann, Paris (1933).

[4] Hrimiuc, D. and Shimada H, On the L duality between Lagrange and Hamilton Manifolds, Nonlinear World, no. 3, (1996), 613-641.

[5] Igarachi, T., Lie derivatives in Cartan spaces, Tensor, N. S., 52 (1993), 80-89.

[6] Igarachi, T., \((\alpha, \beta)\) - Metrics in Cartan Spaces, Tensor, N. S., 55 (1994), 74-83.

[7] Kropina, V. K., On the projective two-dimensional Finsler spaces with a special metric,(in Russian), Trudy Seminara po Vektornomu i Tenzornomu Analizu, 11 (1961), 277-292.

[8] Lee, I. Y. and Park, H. S., Finsler spaces with infinite series \((\alpha, \beta)\)-metric, J. Korean Math. Society, 41, (3), (2004), 567-589.

[9] Masca, Ioana Monica, Sabau Vasile Sorin and Shimada, Hideo, The L-dual of a Matsumoto space, Publications Mathematicae, vol. 72(1), (2003).

[10] Matsumoto, M., Foundation of Finsler geometry and special Finsler spaces, Kaiseisha Press, (1986).

[11] Matsumoto, M., A slop of a mountain is a Finsler surface with respect to time measure, J. Math. Kyoto Univ., 29 (1989), 17-25.

[12] Matsumoto, M., Theory of Finsler spaces with \((\alpha, \beta)\)-metric, Reports on Mathematical Physics, 31 (1992), 43-83.

[13] Miron, R., Cartan spaces in a new point of view by considering them as duals of Finsler spaces, Tensor, N. S., 46 (1987), 329-334.

[14] Miron, R., The geometry of Cartan spaces, Progress of Math., 22 (1988), 1-38.
[15] Randes, G.; On an asymmetric metric in the four-space of general relativity, *Physical Rev.*(2), 59 (1941), 195-199.

[16] Rund, H., The Hamilton-Jacobi theory in the Calculus of Variations, *D. Van Nostrond Co.*, London, (1966).

[17] Sabau Vasile Sorin and Shimada,Hideo ,Classes of Finsler spaces with $(\alpha, \beta)$-metrics, *Reports on Mathematical Physics*, vol. 47, (2001), 31-48.

[18] Sabau Vasile Sorin and Shimada,Hideo, Errata for the paper Classes of Finsler spaces with $(\alpha, \beta)$-metrics, *Reports on Mathematical Physics*, vol. 51, (2003), 149-152.

[19] Tripathi, Brijesh Kumar and Chaubey, V . K., Nonholonomic frames for Finsler space with infinite series of $(\alpha, \beta)$- metric, *Annals of the University of Craiova, Mathematics and Computer Science Series*, 47, (2), (2020), 308-313.

[20] Tripathi, Brijesh Kumar . Nonholonomic frames for Finsler space with deformed $(\alpha, \beta)$- metric, *Italian Journal of Pure and Applied Mathematics*, 41, (2019), 663-670.

**Author information**

1Brijesh Kumar Tripathi, Department of Mathematics, L.D. College of Engineering, Ahmedabad, Gujarat-380015., India.
E-mail: brijeshkumartripathi4@gmail.com

2V. K. Chaubey, Department of Applied Sciences,Buddha Institute of Technology, GIDA , Gorakhpur, U.P.-273209., India.
E-mail: vkcoct@gmail.com

Received: April 15, 2021
Accepted: September 18, 2021